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Improvements in the locomotive blast pipe,

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I. — The function of the blast.

The steam locomotive, amongst other things, is characterised by the eminently simple manner in which the draught is obtained, i. e., by directing the steam exhausted from the cylinders up the chimney.

This solution, which at first sight may appear crude, meets in fact the desired conditions to the maximum, since it solves the most difficult of all problems, that of automaticity.

The draught, i. e. the weight of air drawn each interval of time through the grate, depending on the quantity of steam which is exhausted in a given time through the blast pipe, we can conceive that there may be some relationship between the weight of steam consumed and the weight of steam produced by the boiler, since the exhaust steam is able to draw in the exact quantity of air needed for the combustion of the weight of coal able to evaporate a quantity of water equal to that which has been lost.

Consequently the staff does not have to alter the draught according to the rate of evaporation required, its duty being limited to firing the boiler and looking after the water so as to keep the pressure up to blowing off point and the water level to the desired point.

In view of the essentially variable power demanded of the locomotive, it is easy to undertstand the impossible task the drivers and firemen would have to perform if the present blast pipe of locomotives were replaced by some arrangement which was not automatic in action.

This condition has, however, arisen in some instances and possibly may have had some part in the little favour turbine locomotives have met with so far.

Having made these general remarks we will deal below in detail with the role of the locomotive blast.

If the working of the boiler is considered, it may be represented by a curve No. (1), figure 1, which will give, for example, the weight Q of steam produced per hour as a function of the quantity C of fuel burnt in the same time per square metre of grate area for example.

As the combustion demands the intro-

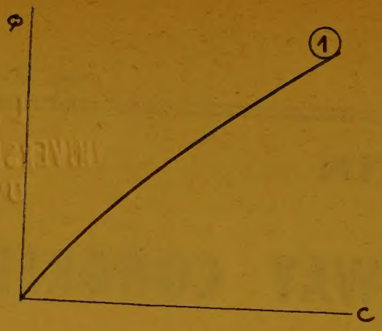

Fig. 1.

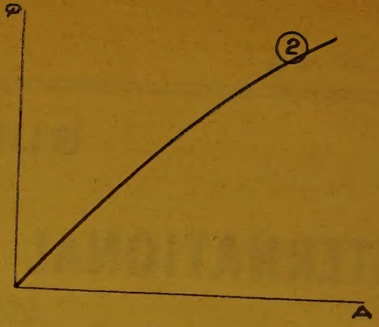

Fig. 2.

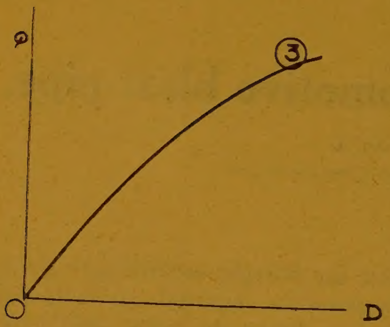

Fig. 3.

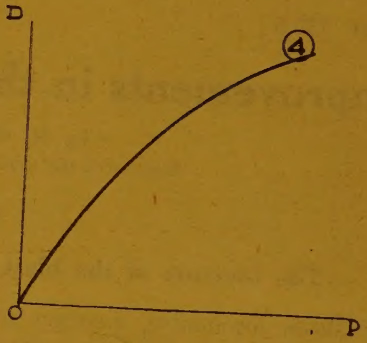

Fig. 4.

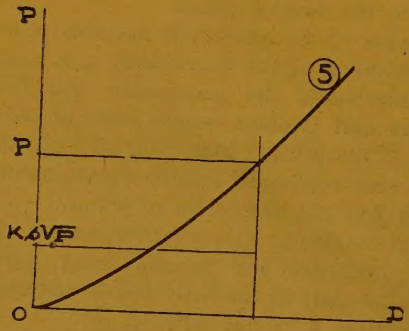

Fig. 5.

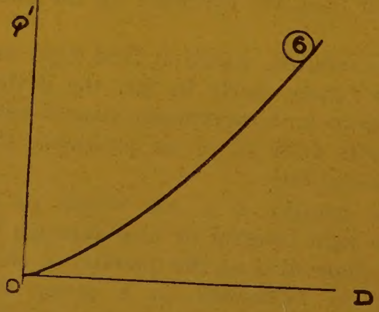

Fig. 6.

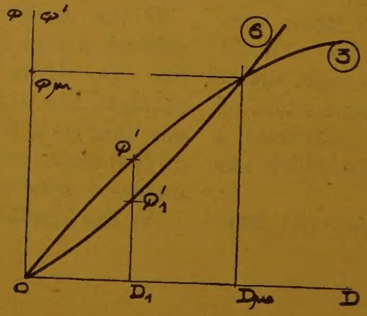

Fig. 7.

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duction into the firebox of a weight of air A, we can replace the curve (1), figure 1, by a curve (2), figure 2, giving the weight of steam produced per hour as a function of the weight of air A introduced into the firebox in the same time.

The weight of air introduced A depends in its turn on the vacuum D produced in the smoke box by the blast, since A is proportional to $\sqrt{D}$.

This makes it possible to substitute curve (3), figure 3 for curve (2).

But as the vacuum D depends, for each type of blast used, on the back pressure P in the blast pipe, the relation which connects D and P can be ascertained experimentally by measuring the corresponding values of D and P, and can be represented by the curve (4), figure 4, or by the curve (5), figure 5, by inverting the ordinates and abscissæ. P itself depends, for a constant value (*s*) of the section of the blast pipe top, upon the weight of steam Q exhausted in unit time, since Q is proportional to

$$s\sqrt{P}$$

Curve (5) can therefore be replaced by curve (6), figure 6, using as ordinates

$$Q' = K s \sqrt{P} \qquad (1)$$

K being a constant.

Superimposing figures 3 and 6, we obtain figure 7 which clearly shows the relationship which ought to exist between the characteristics of the blast and those of the boiler for the latter to be kept in action. Curve (6) shows the weight of steam Q′ required for the blast to produce the vacuum D in the smoke box, and the curve (3) the weight of steam Q_1 the boiler will produce when the vacuum D_1 has been created.

As the quantities Q_1 and Q'_1 are equal, the steam produced by the boiler passing through the blast pipe, we see that for all vacua between 0 and D_m the quantity of steam needed for the proper working of the blast being less than the quantity of steam the boiler is capable of producing, the latter can be pushed progressively without it being necessary to touch the blast pipe until the vacuum reaches the value D_m corresponding to the intersection of curves (3) and (6). This point of intersection corresponds to the maximum production of steam Q_m obtainable with the blast considered.

The relation so brought out between the productive power of the boiler and the blast used is of capital importance because it shows that the apparent lack of capacity of a boiler can be due not only to too small dimensions but also to the use of a badly designed or fitted blast.

To use the full power of which a boiler is capable, it is necessary that the blast should be such that its characteristic curve (6) crosses the curve (3) of the boiler evaporation, for the greatest possible values, of the vacuum D_m or of the weight of steam produced Q_m.

Such a condition can be got with a given type of blast, by a suitable reduction of the section (*s*) of the blast pipe.

The amount of movement of the steam which is exhausted is in this way increased, and theory, confirmed by experience, shows that the vacuum in the smoke box is increased at the same time.

There is however a limit to this increase, as the efficiency of the ejector formed by the blast pipe and the chimney decreases when the speed of the gases increases, so much so that reducing (*s*) only produces a slight effect which becomes still less as (*s*) becomes smaller.

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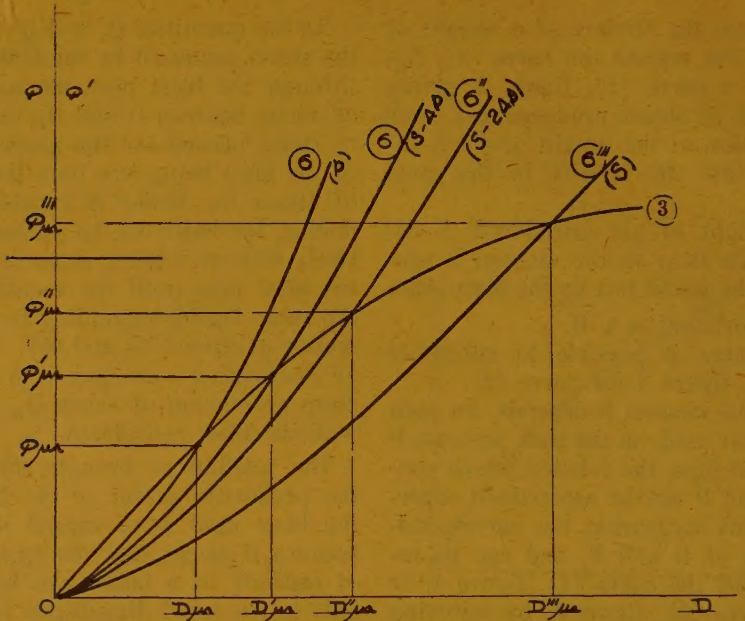

Fig. 8.

(*Note.* — Curve (6) between (6) and (6'') should be marked (6').)

This is shown by curves (6') and 6'') of figure 8.

The reduction of the blast nozzle has, in addition, a serious drawback, as the back pressure

$$P = \frac{Q'^2}{R^2 \, s^2}$$

according to formula (1) increases inversely as the square of the section of the blast pipe and reduces appreciably the work done by the steam in the cylinders of the engine.

In this connection it will be remembered that in the case of a locomotive having two cylinders 700 mm. (27 1/2 inches) in diameter and a stroke of 650 mm. (25 5/8 inches) with driving wheels 1.90 m. (6 ft. 2 13/16 in.) in diameter, 100 gr./cm^2 (1.42 lb. per sq. inch) of back pressure absorbs 60 H. P. at the speed of 120 km. (75 miles) an hour.

If, for instance, 800 gr./cm^2 (11.38 lb. per sq. inch) of back pressure is needed for producing at full power, a vacuum of 250 mm. (10 inches) of water with a particular type of blast, the use of another design only needing 400 gr./cm^2 (5.69 lb. per sq. inch) of back pressure will make it possible to develop an additional 240 H. P., which will almost all be available at the drawbar as the running resistance of the engine will not have varied.

If, in the case considered, the locomotive developed 1 500 H. P. for example at the drawbar, it would develop 1 740 after changing the blast pipe, that is a gain of

16.6 %, which would enable the engine to haul 700 tons on the level instead of 600, at the speed of 120 km. (75 miles) an hour.

This example shows the importance of a well designed blast, especially in connection with high speeds.

We must, therefore, endeavour to find the blast which will give the greatest vacuum with the least back pressure and having a characteristic curve such a $(6''')$, figure 8, with which the full power of the boiler can be obtained without excessive back pressure.

The respective forms of curves (3) and (6) give rise to an important remark.

These curves actually have a very slight curvature, so that for neighbouring values (s) or $(s\Delta s)$, selected for the section of the blast pipe top, the boiler's productive power may be limited to a very low value $Q^1{}_m$ or on the contrary to a very different value $Q^2{}_m$, which allows it to work normally.

This shows that it is necessary to adjust the blast pipe diameter very accurately for each locomotive, an adjustment which is considered as having been done when the engine steams freely at all rates of working. This remark quite naturally leads us to the case of the variable blast pipe top, the usefulness of which appears to be limited.

The variability has in fact but one object, that of being able to change as desired, for example from one curve such as (6_1), figure 6, to another such as (6_2), or inversely. As these curves by the nature of things lie very closely to one another, when they correspond to real working conditions of the boiler, we see that the effective use of the variable blast pipe top is extremely restricted, so restricted in fact that even once the position of the blast pipe corresponding to satisfactory evaporation at all working rates has been found the drivers need not alter it. It must, moreover, be admitted that in practice most variable blast pipes are handled in this way.

The variability would be justified in the case in which the characteristic curve of the blast would differ markedly from that of curve (6_2), figure 9. Obviously with characteristic curves such as (7) or (8), figure 10, the variable blast pipe top would be necessary, since for a vacuum of less than $D_m 7$, the blast corresponding to curve (7) would not give sufficient draught, and that corresponding to curve (8) would give a quite excessive draught below $D_m 8$.

Actually such blasts are extremely rare, and even when corrected by making full use of the variable blast pipe top, their use would be quite unreliable in service as the staff would have to be changing the opening continually according to the cut-off and the speed, a task that the very principle of the locomotive blast happily renders unnecessary.

When the causes of insufficient steaming capacity of a boiler are examined and the failure is attributed to the blast, it is essential to distinguish carefully in view of what we have written above, between the case in which we have a good blast with characteristic curves (2), figure 11, but insufficiently restricted, or on the contrary with a badly designed blast of characteristic curve (1), figure 11, which even when very restricted does not give sufficient draught. In such a case the form of the characteristic curve will generally make it easy to recognise the cause of the bad result obtained.

The productive power of the boiler can also have a limit in the inverse sense, in which the blast being too violent either through its high efficiency or through an excessive reduction in the area of the blast pipe top, the speed of the air pass-

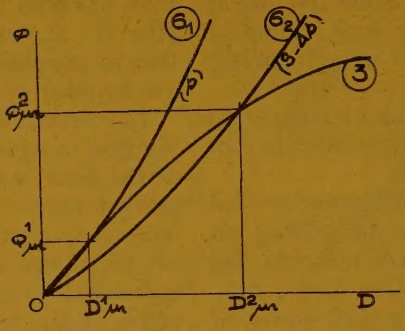

Fig. 9.

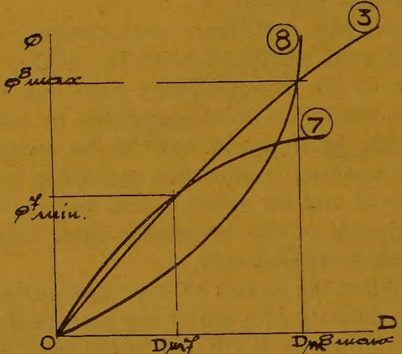

Fig. 10.

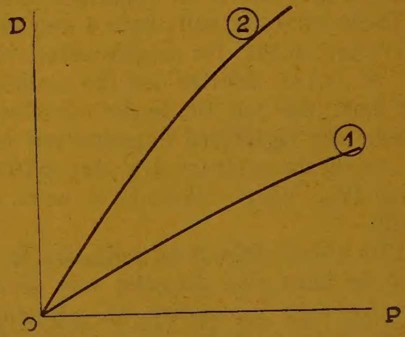

Fig. 11.

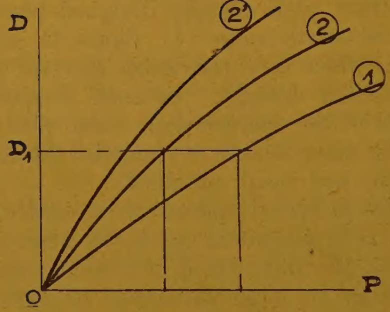

Fig. 12.

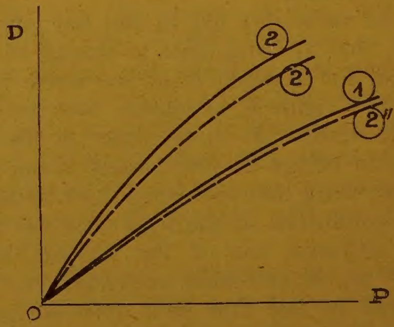

Fig. 13.

ing through the bed of fuel above the grate is such that the dynamic pressure resulting lifts the fire, tears it up and carries it away, making it impossible to keep it in good order.

In this case two alternatives are available :

The draught is greater than is strictly needed to burn the coal. All that is required is to adjust the area of the blast pipe top until the desired result is obtained, which will moreover improve the actual efficiency of the blast and raise its curve in terms of (D.P.).

Or the draught produced, in spite of its violence, is actually necessary to maintain the rate of combustion needed, and in this event the tearing up of the fire proves that the grate area is too small to burn the coal in the form provided. In such a case larger size coal should be used *or such rates of evaporation should not be expected with the boiler considered.*

So far we have considered the relationship which ought to exist between the intensity of the draught produced by the blast and the evaporative power of the boiler.

There is another very important point to be considered : the way in which the draught is distributed over the whole of the grate area, upon which distribution depends in turn the method of firing, the fuel efficiency, and finally the evaporative power for a given smoke box vacuum.

The ideal would obviously consist in having a draught which is uniformly distributed over the whole surface of the grate; it would then be possible to have *a fire of the same thickness all over the grate.*

The combustion would take place with the same intensity at each point without dead areas where clinker generally begins to form and ends by blocking the draught; the grate area would be used to its maximum without excessive draught, hence lower losses through sparks; the boiler would steam easily and freely.

In order to tend towards this result, use must be made of blasts with multiple suction points suitably positioned in front of the tube plate so as to make as equal as possible the quantity of combustion gases drawn through each line of smoke tubes. As this quantity depends, for a given tube, not only on the suction produced in it by the exhaust, but also on the resistance encountered by the gases discharged by the tube considered in passing through the ash pan, grate, fuel bed, brick arch, and the tube itself, we see that the suction effect required of the blast will not be the same on all the tubes but may vary from tube to tube according to the arrangement of the boiler.

With a blast formed of a simple exhaust pipe placed under the chimney forming a single suction stage, it will generally be impossible to get perfect uniformity of combustion over all the grate, even if the dimensions and arrangement of the brick arch have been given attention or by using a grate with variable air openings, an arrangement which is not without its complications.

With a blast with two or three suction stages, such as when using the American petticoat arrangement, by selecting the relative position and dimensions of these petticoats with regards to the sometimes very varying resistances of the circuits taken by the combustion gases drawn through the different parts of the nest of tubes, sufficiently satisfactory uniform combustion can be obtained.

From this point of view, superheated engines sometimes give rise to some difficulty when, as frequently happens, the resistance to the passage of the gases through the flue tubes is much higher than that through the smoke tubes.

This defect is corrected by increasing the draught across the flue tubes and by using a brick arch more or less raised at the back end.

When the nests of tubes are alike and the ash pans are well designed, the arches can be made lower at the back, and the draught produced by the blast should be at each level as regular as possible.

Differences in the resistance offered to the passage of the combustion gases through the boiler call for further remarks.

When comparing the characteristic curves of two blasts obtained from tests on the same locomotive, it is usual to argue as if the vacuum D_1 measured at the same point in the smoke box corresponded to the same weight of air drawn in, i. e. to the same draught with the two types.

This would be correct if the two blasts produced in front of the tube plate suction zones of like configuration and intensity. A distinction must therefore be made between the blasts of the single suction type and those having multiple suction points.

The latter, for a lower suction intensity at all points, will result in fact in a greater total discharge of gases because all the tubes will discharge equal amounts.

Consequently the vacuum measured in the smoke box will be smaller because the gases will flow into it in greater volume.

The behaviour is therefore the same as if the resistance to the flow of the combustion gases through the boiler had been reduced.

Although at first sight it appears paradoxical, experience has shown that a blast pipe with several petticoats gives a greater draught than one with a single petticoat for a given average smoke box vacuum.

The characteristic curve (2), figure 12, of a multiple petticoat pipe arrangement should really be drawn as in (2′), to remain comparable with curve (1), taken as corresponding to a blast with a single suction point.

It will also be readily appreciated that the use of an even and thin fire with a uniformly distributed draught will offer less resistance to the passage of the gases and will give similar results.

Following the same order of ideas, it should be remembered that two characteristic curves in terms of (DP) corresponding to two different types of blast are only exactly comparable *when giving equal draught*, i. e. when for a given discharge of steam through the blast pipe top the total weight of air A drawn through the grate remains the same, which can always be ensured by using blast pipe tops of suitable sections.

In practice however this is rarely the case and when a blast is replaced by an improved one, the latter is usually called on to produce a greater draught because thereby the engine is easier to fire and the output of the boiler is increased.

This result is readily obtained by using a rather smaller blast pipe top than that really needed, and as this increases the speed of the gases through the smoke box and as the losses of energy vary as the square of the speed of the gases, the efficiency of the blast is slightly reduced and in place of the characteristic curve (2), figure 13, strictly comparable with curve (1), we have a curve (2′) below (2) which does not give a really exact idea of the relative value of the blasts (1) and (2). It may even be that in cases in which the blast (1) is quite inadequate the curve (2) may take the position (2″) below curve (1).

We see, therefore, that for two reasons:

1. the greater ease with which the gases pass through the boiler when the blast produces a well distributed draught,

2. the increase of draught generally required of an improved blast, because this increase is obtained without and disadvantage,

the characteristic curves in terms of (DP) or a well designed blast with multiple suction points, when compared with the characteristic curve of a more ordinary single suction point arrangement, give an idea of the advantage actually obtained with the more perfected blast exhaust which is less than the actual.

II. — Importance of the blast.

The preceding considerations enable us to appreciate the role of the locomotive blast and its importance has been made clear.

The power and the thermal efficiency of the boiler, which depend both upon the quantity of coal which can be burnt on the grate and the more or less perfect combustion obtained, are thus directly dependent upon the more or less efficient working of the blast.

The consequences resulting from the use of a defectively designed or badly set blast are incalculable, as the power of the engine is limited to figures sometimes very low, and the fuel composition is increased in frequently unsuspected proportions.

Many locomotives in service, owing to their defective blast pipe arrangement, are not capable of doing as much work as would be expected from their dimensions and their cost of construction. The coal consumption per 100 ton-kilometres of these engines is excessive because of the inefficient combustion of the fuel and because they cannot be used to full capacity.

For these reasons, the most highly developed locomotives are today still unable to do the work expected of them if the blast pipe is badly designed or fitted.

When comparing the thermal efficiency of various locomotives the decisive role which the proper adjustment of the blast pipe plays in the values of these efficiencies is also often forgotten, so much so that very ordinary engines can sometimes be found competing with advantage with very highly developed types, high-pressure engines, for example, in which the question of the blast pipe arrangement, a particularly delicate one, has not been properly solved.

III. — Different types of blast pipe.

The difficulties frequently encountered in getting an efficient blast and the absence of accurate and precise rules on which to design it have resulted in a considerable number of systems being put forward.

As the very different ideas which have produced so many devices have not revealed sufficiently well established principles for these designs to be classified rationally, we think the case will be met by grouping them into the following four classes :

1. Blast with single suction point, consisting of a blast pipe discharging at the base of the chimney;

2. Blast with multiple points of suction formed of a blast pipe discharging into a petticoat pipe or a series of petticoats interposed between the blast pipe and the chimney;

3. Variable blast pipes, i. e. with the

blast pipe top variable and the arrangement of No. 1;

4. Variable blast pipes in conjunction with the 2nd group.

Finally these different blasts can be applied either as a single arrangement in accordance with the classes given above, or a number of identical fittings arranged in parallel (double chimneys for example).

As we have seen in Chapter 1, the designs with multiple suction points make it possible to better regulate the draught over the tube plate and consequently over the grate; in addition, compared with the simple blast pipe, they also enable the losses resulting from the changes of speed of the steam and gases before reaching the atmosphere to be reduced.

The variable blasts make it possible to vary at each moment the section of the passage taken by the steam through the blast pipe, and consequently the draught, for a given weight of steam exhausted from the cylinders.

We have shown in Chapter I that a variable blast pipe top is not essential and in fact this arrangement is only found on a decreasing number of engines (1).

The instances in which a variable blast pipe may be of value are in fact rare; these tops are more complicated, more liable to get out of order and involve additional first cost and maintenance. It may be asked if their problematical advantages are sufficient to justify their use.

IV. — Nature of the problem presented by the locomotive blast.

This problem is a double one.

It relates to the energetics and mechanics of fluids so far as concerns the adaptation of the draught producing equipment to each particular type of locomotive; the objective looked for is an arrangement capable of drawing through the grate and discharging to the atmosphere the gaseous products necessary for the working of the machine or resulting therefrom, this function naturally having to be accomplished with the minimum expenditure of energy. This result is obviously obtained when for a given draught the back pressure due to the blast is the minimum.

The solution of the blast problem is also the result of experience as regards the best form of nozzle, of the intermediate petticoats, and of the chimneys having regard to the conditions most favourable to the intimate mixture of the entraining fluid, the steam, and the fluid entrained : the products of combustion; experience also determines the best relative positions for these same parts so that they do their work in the best possible way, taking into account the particular form, which cannot be determined theoretically beforehand, taken by the steam jets and the gaseous mixture on leaving the nozzle and the petticoat pipes.

We are finally led to considering the action of the blast as being made up of the following two more or less clearly differentiated functions according to the types considered :

1. *Mixing function,* having as its object the intimate mixture between the entraining steam and the gases drawn in, a function the complete carrying out of which is the basis of all theory of the

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(1) The Belgian and Italian railways which formerly used variable blast pipes to a large extent have replaced the whole of them by fixed tops. The same is found on other railways which at one period fitted variable blast pipes on some of their engines.

blast and which decides to a large extent the proper working of the arrangement used.

2. *Exhausting function discharging the gases* to the atmosphere, involving work in raising the pressure of the products of combustion from that at which they exist in the smoke box to that of the atmosphere.

The first of these functions is essentially of a physical nature and so far it has not been found possible to express it by any equation. The parts concerned in this function should therefore be arranged for the present almost solely in accordance with the dictates of experience.

The second function depends more directly upon mechanics and the parts affected can be arranged and dimensioned according to more positively established rules.

The improvements made in the locomotive blast from its origin have been relatively slow, and most locomotives are still fitted with the oldest and simplest blast, consisting of a plain blast pipe which discharges the steam into the chimney.

If we consider how these blast pipes are proportioned we soon become convinced that the most empirical and sometimes most widely divergent rules have been followed when designing them. This is to be regretted, as many locomotives suffer, and sometimes seriously, from blast pipes wrongly proportioned.

The general rules of the mechanics of fluids are however applicable to a large extent to the calculation of these dimensions and, provided suitable constants, the values of which are to be obtained from practical experience, are used, it is always possible to give the blast pipe and chimney dimensions quite close to those which are in fact the best.

When considering the design of the blast, the problem therefore is not simply one of selecting the most efficient arrangement in itself, but also deciding the best dimensions to give to the detail parts forming this blast for it to give effectively, on the locomotive considered, the desired result.

V. — The Kylchap blast.

Among the most highly perfected blasts, whether due to their arrangement or to the bases on which they have been designed, special mention must be made of the Kylchap which since its recent introduction has been fitted to more than one thousand locomotives belonging to different railways.

This blast arrangement, which was very completely dealt with in the *Revue Générale des Chemins de fer*, August and September 1928 numbers, is a blast with multiple suction points and consists of :

1. A rigid or variable blast pipe top fitted with short bars which are fixed in the case of the rigid top, and moveable on the variable type;

2. One or several divided up petticoat pipes of special shape dividing the gaseous jet into several separate streams;

3. One cylindrical petticoat pipe immediately below the chimney type (n K/C) or a simple bell mouthed chimney suitably proportioned (type n K/T) (1).

In this design of exhaust, the *mixing function* is mainly expected of the blast pipe top and the short bars in it, and to the one or series of divided up petticoat pipes fitted immediately above it.

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(1) n K signifies that there are « n » divided up petticoat pipes in series with at the top either a single cylindrical petticoat pipe (1C) or a bell mouthed chimney (T).

The function of the *discharge of the gases* to the atmosphere is covered by the cylindrical petticoat and the chimney in the (n K/1C) type and the bell mouthed chimney in the (n K/T) type.

The fairly well-defined separation in this blast arrangement between the functions covered by its various parts makes it possible to calculate the dimensions and to adapt them to the most widely varying types of locomotives with the minimum of error.

The slight uncertainty which still exists in regard to the optimum section to give to the blast pipe top for the class of coal to be used and the service to be worked can always be dealt with in service when finally adjusting the blast pipe top.

B. — *Actual examples.*

Figures 14 to 18 show a number of applications of the Kylchap blast.

In all classes *t* is the blast pipe top with short projecting bars, K the divided up petticoat or series of petticoat pipes, C the cylindrical petticoat pipe immediately under the chimney in the n K/1C type, and T the bell mouthed chimney in the n K/T type.

Figure 14 shows the 1K/1C design of a metre-gauge compound 0-6-0+0-6-0 *Mallet* engine, with a grate area of 1.485 m^2 (16 sq. feet) and a boiler pressure of 14 kgr./cm^2 (199 lb. per sq inch).

Figure 15 illustrates the 1K/1C design of a standard gauge 4-6-0, four cylinder

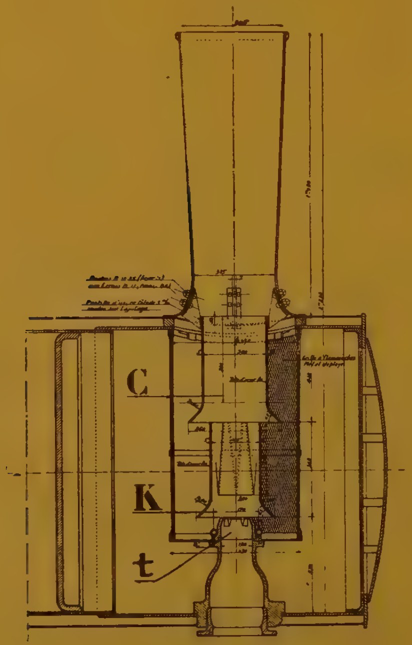


Fig. 14.

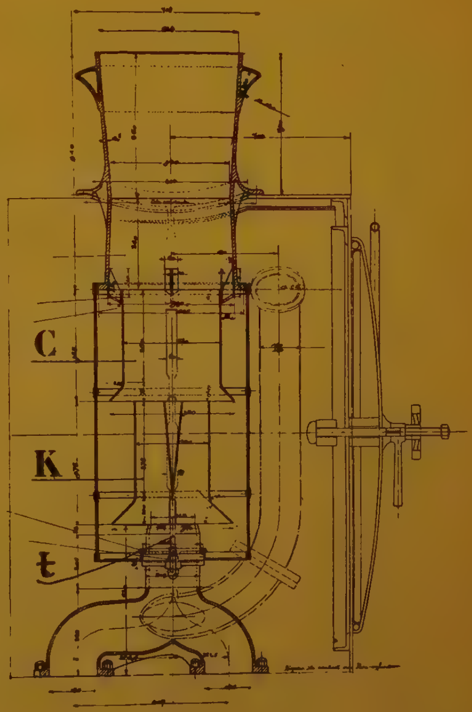


Fig. 15.

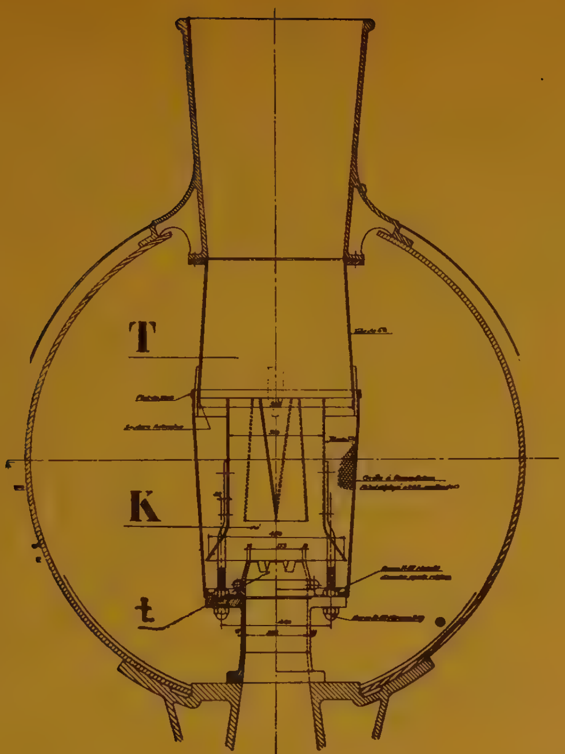


Fig. 16.

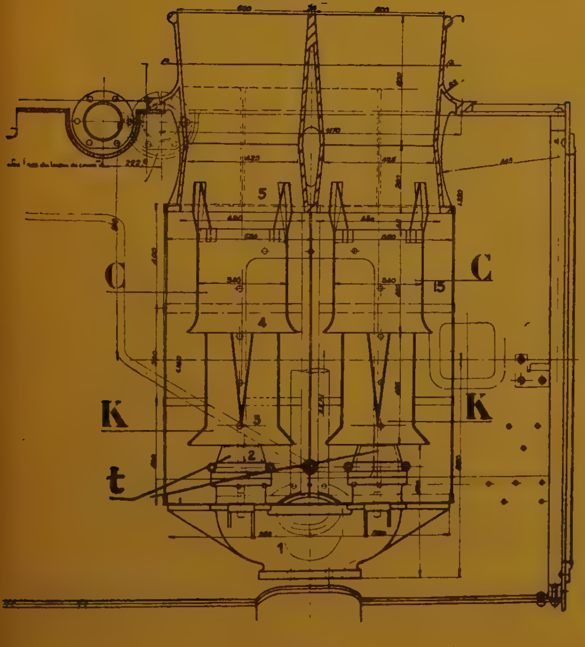


Fig. 17.

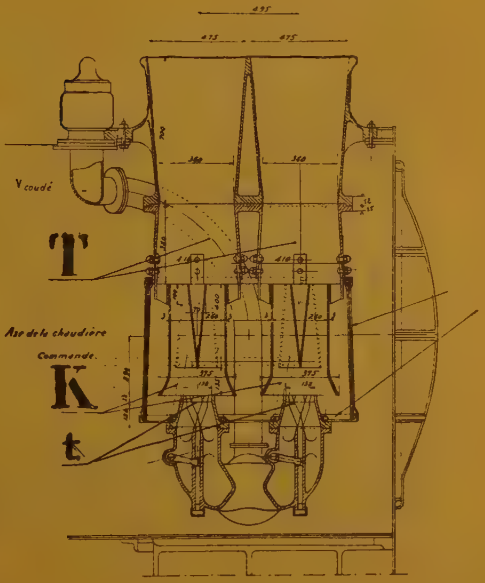


Fig. 18.

simple expansion superheated locomotive with 3.13 m² (33.7 sq. feet) grate area and a boiler pressure of 14 kgr./cm² (199 lb. per sq. inch).

Figure 16 relates to the 1K/T design for a standard gauge 4-cylinder compound saturated steam 4-6-2 locomotive with 3.96 m² (42.6 sq. feet) of grate area and 16 kgr./cm² (227.6 lb. per sq. inch) boiler pressure.

Figure 17 is a 1K/1C-1K/1C design for a standard gauge 2-cylinder simple expansion superheated 4-6-2 locomotive with 4.50 m² (48.4 sq. feet) grate area and 20 kgr./cm² (284.5 lb. per sq. inch) boiler pressure.

Figure 18 shows the 1K/T-1K/T variable design for a standard gauge 4-cylinder superheated compound 4-8-2 type locomotive having a grate area of 5 m² (53.8 sq. feet) and a boiler pressure of 16 kgr./cm² (227.6 lb. per sq. inch).

C. — *Results obtained.*

a) *Characteristic curves.*

The characteristic curves of the « Kylchap » blast giving the vacuum D in the smoke box in terms of the back pressure P in the blast pipe show the definitely higher efficiency of this design relatively to the other systems previously used.

The curves of plates I, II and III, taken from engines of all types and of widely different power, first with their original layout and subsequently with the « Kylchap » show in all cases the superiority of this latter whatever type is taken as the basis of comparison.

Two particularly interesting cases are those of curves 3 and 4, plate III, which demonstrate the superiority of the « Kylchap » blast, not only over designs with one suction point, but equally over the designs with two petticoat pipes from which at first sight it appears to differ least.

In the case of curve 3 the blasts compared only differed in the type of petticoat fitted immediately above the blast pipe top.

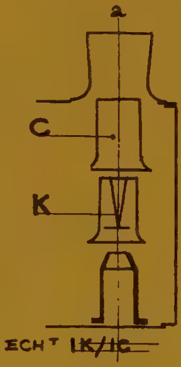


Fig. 19*a*.

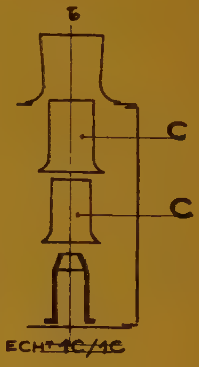


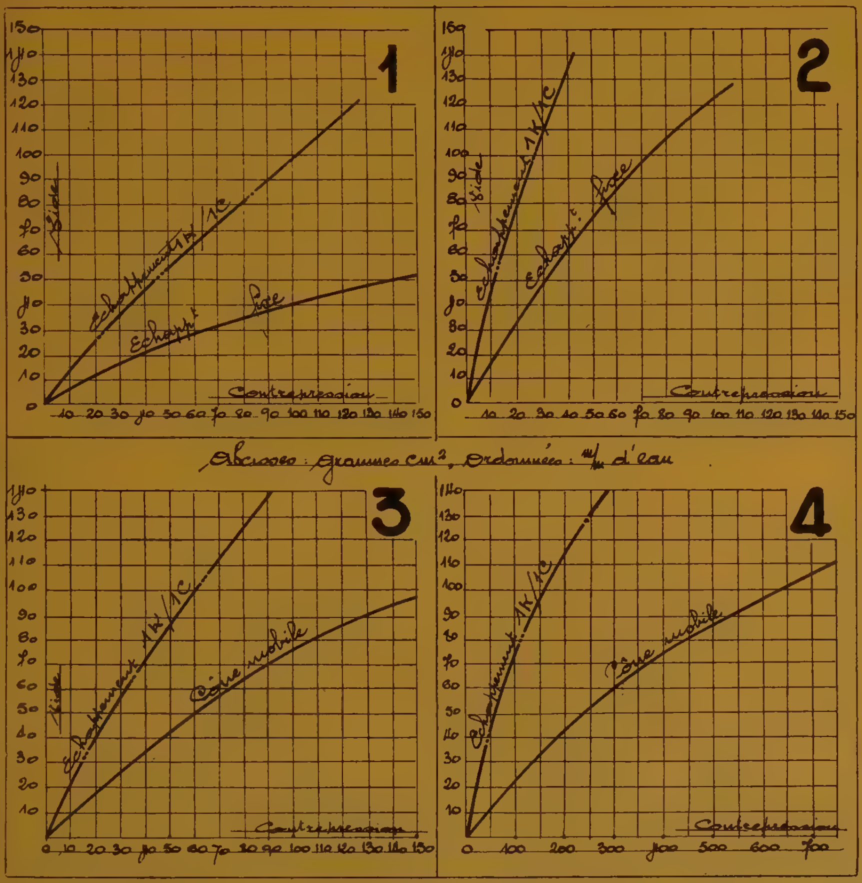
Fig. 19*b*.

In one of the arrangements investigated (fig. 19*a*) this petticoat K was of the divided up type (design 1K/1C) and in the other the petticoat C was cylindrical and of the same total section as the petticoat K (fig. 19*b*) (design 1C/1C) so as not to change in any way the conditions under which the gases flowed. The position of this petticoat was in addition so chosen that it completely filled the function assigned to it and gave the optimum result.

The definitely greater efficiency of the 1K/1C design was shown by *an increase at equal boiler evaporation* of 50 % in the draught for the same back pressure in the blast pipe column.

Curve No. 4 of plate III relates to an analogous case. As the double petticoat blast arrangement fitted to the locomotive considered in place of the original fixed ordinary type had not given quite the expected evaporative power, the « Kyl-

Plate I.

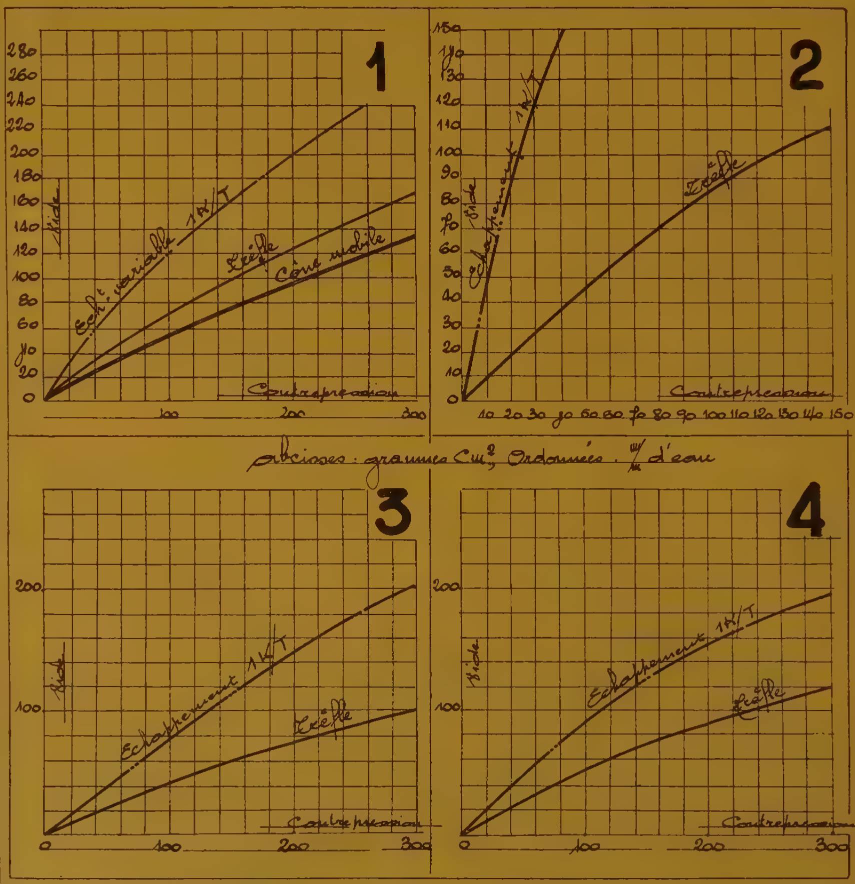


—	Type of locomotive.	Characteristics.	Service.	Pressure, kgr./cm² (*lb./sq. in.*)	Grate area, m² (*sq. ft.*)	—
Curves **1**	2-8-0	Simple expansion.	Goods.	13.5 (*192.0*)	3.05 (*32.8*)	Superheated.
Curves **2**	4-6-0	Simple expansion.	Passenger.	12.0 (*170.7*)	2.40 (*25.8*)	Superheated.
Curves **3**	0-6-0 + 0-6-0	Compound.	Goods.	16.0 (*227.6*)	3.00 (*32.3*)	Saturated.
Curves **4**	2-8-0	Simple expansion.	Goods.	12.0 (*170.7*)	3.03 (*32.6*)	Superheated.

Explanation of French terms in plate 1 :

Vide = Vacuum. — Echappement fixe = Fixed blast pipe top. — Abcisses : grammes cm², Ordonnées : m/m d'eau = Abcissae : grammes per square centimetre, ordinates : millimetres of water. — Cone mobile = Adjustable cone-shaped blast. — Contre-pression = Back pressure.

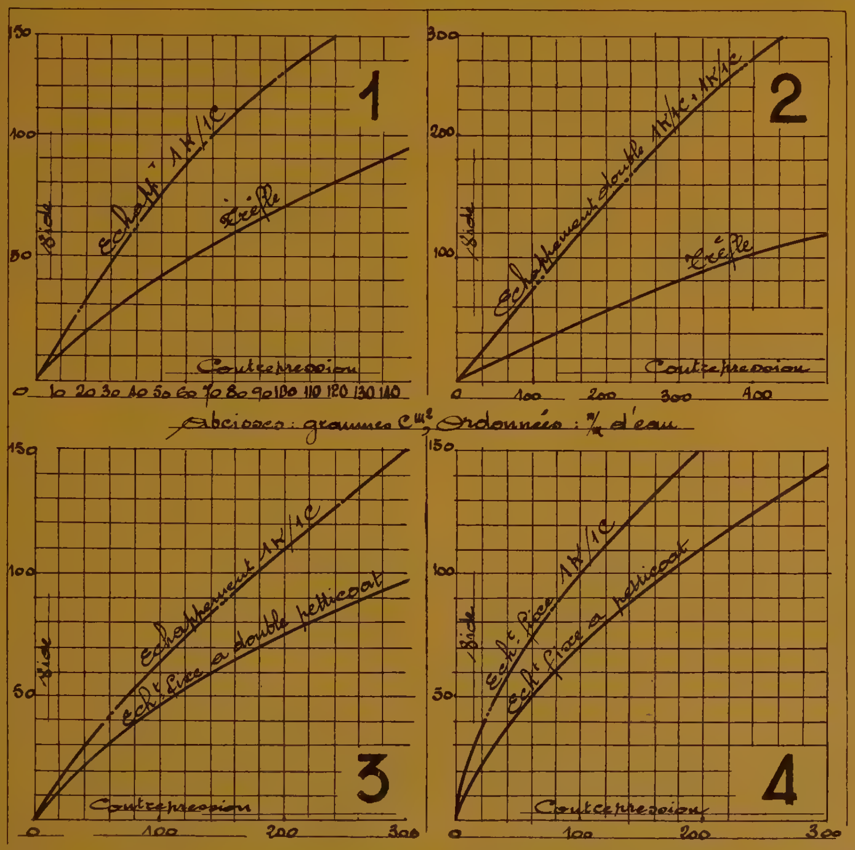
Plate II.



—	Type of locomotive.	Characteristics.	Service.	Pressure, kgr./cm² *(lb./sq. in.)*	Grate area. m² *(sq. ft.)*	—
Curves **1**	4-6-2	Compound.	Express.	16.0 *(227.6)*	3.50 *(37.7)*	Superheated.
Curves **2**	4-6-2	Do.	Do.	16.0 *(227.6)*	3.96 *(42.6)*	Saturated.
Curves **3**	4-6-2	Do.	Do.	16.0 *(227.6)*	4.27 *(45.9)*	Superheated.
Curves **4**	4-8-2	Do.	Do.	17.0 *(241.8)*	4.43 *(47.7)*	Superheated.

Note : Trèfle = Clover type.

Plate III.



—	Type of locomotive.	Characteristics.	Service.	Pressure, kgr./cm² *(lb./sq. in.)*	Grate area, m² *(sq. ft.)*	—
Curves **1**	4-6-2	Compound.	Goods.	16.0 *(227.6)*	3.80 *(40.9)*	Superheated.
Curves **2**	4-6-2	Compound.	Express.	16.0 *(227.6)*	4.27 *(45.9)*	Do.
Curves **3**	4-6-2	Compound.	Do.	16.0 *(227.6)*	4.27 *(45.9)*	Do.
Curves **4**	4-6-0	Simple expansion, 4-cylinder.	Do.	14.0 *(199.1)*	3.0 *(32.3)*	Do.

Note : Echapt fixe à double petticoat = Fixed blast pipe top with double petticoat.

chap » (1K/1C) blast was tested and the full desired steam production was obtained with appreciable savings of fuel (12 %).

The increase in the draught for a given back pressure in the blast pipe was slightly less than in the preceding case, as advantage was taken of the low back pressure with the new blast to reduce the blast pipe top and *obtain full output from the boiler*. This, as we pointed out in Chapter 1, is what usually happens with an improved blast so that it must be noted that their characteristic curves appear to show less improvement over the ordinary types than is actually the case.

These examples show the very definite superiority of the divided up petticoat pipes of the « Kylchap » blast over the ordinary petticoats which latter do not act as mixer so well as the divided up type.

b) *Proportionality of the action of the blast to the production of steam.*

We saw in Chapter 1 that the action of the blast should assure the automaticity of working of the boiler so that the production of steam always made up the consumption, an absolute condition for the maintenance of a constant boiler pressure under all running conditions.

These desiderata, which are theoretically obtained with the locomotive blast, are however imperfectly realised with certain types of blast which are defective in action.

For this reason certain engines only steam well for certain cut off positions, between fairly narrow limits in some cases, and this encourages the drivers to wire-draw the steam at the regulator to regulate the power of the engine to the detriment of the efficiency of the engine as the latter is then working with low pressure steam only.

A similar state of affairs exists on many compound locomotives which only steam well at late low pressure cut offs and consequently do very little work in the low pressure cylinders, so that the use of compounding becomes sometimes open to criticism.

Experience has shown that the « Kylchap » blast is free from these drawbacks.

With this blast the earliest cut offs can be used on simple expansion engines which can run with full regulator and so make use of the full boiler pressure, an essential condition for the proper working of high-pressure engines.

On compound engines it is also possible to get all the full steam production desired with very early L. P. cut offs such as for example 40 % and even 30 %, if the locomotive has been suitably designed, to avoid the disastrous effects of wire-drawing on the efficiency of the locomotive at high speeds.

c) *Rate of firing. Sparks. Types of fuel usable.*

As the « Kylchap » blast is designed with multiple suction points, it can be so proportioned in all cases, even when the resistance through the tubes is not uniform, as to distribute as evenly as possible the draught through the tubes and consequently over the whole grate area.

This result is obtained with grates of all shapes, narrow, long, and very long (3.80 m. = 12 ft. 5 5/8 in.), wide or extended, either rectangular or square, or trapezoidal, narrow at the front end and extended over the frames on the back.

Under these conditions the fire can be about the same thickness over the whole of the grate, the thickness varying from 10 to 15 cm. (4 to 6 inches) on easily worked trains to 30 to 40 cm. (12 to

16 inches) at high rates of combustion [500 to 800 kgr./m² (102 to 164 lb. per sq. foot) of grate area per hour].

This method of firing reduces the formation of clinker and the amount of char carried into the smoke box to a minimum; the efficiency of the combustion is the maximum and, thanks to the fuel bed remaining open, it is possible to run the longest trips [450 km. (280 miles) for example] at the heaviest rate of combustion, without it being necessary to drop the fire.

It has been found in many instances that locomotives burning coal with which the fire has to be cleaned after short distances with all the ordinary types of blast, can be run more than double the distance when fitted with the « Kylchap » blast.

For the same reason engines fitted with the fixed « Kylchap » blast have been able to cover the service (¹) satisfactorily when engines fitted with variable blast pipes of other designs gave definitely inferior results, the variability being unable to maintain the rate of combustion at the required rate on a grate on which it had not been possible to avoid clinker forming owing to the draught not being uniformly distributed and not strong enough under all working conditions.

In addition, with the « Kylchap » blast it has been found possible to get the best results with fuels of all kinds.

With coals of high sulphur content, of low calorific value (4 500 calories = 9 100 B. T. U.) with very fusible ash, which usually have to be burnt in conjunction with wood to prevent the formation of clinker which quickly blocks up the grate, the engines steamed well when using this coal alone, the clinker swelling up in the fire and remaining open, and thereby not preventing air passing through the grate.

Excellent results have also been obtained with shales of low calorific value (4 000 to 4 500 calories = 7 200 to 9 100 B. T. U.), with lignite and with wood.

d) *Maintenance of the pressure and of the water level in the boiler.*

In all cases in which the pressure and the water level can only be maintained with difficulty, whether because the blast is not efficient, or because the boiler is working near its limit of capacity, marked improvement usually results from using the « Kylchap » blast.

This is shown by the curves of figures 20 and 21, relating the former to a four-cylinder saturated steam articulated compound locomotive with a grate of 3 m² (32.3 sq. feet) area and a boiler pressure of 16 kgr./cm² (227.6 lb. per sq. inch), and the latter (fig. 21) to a high-pressure locomotive with a boiler pressure of 60 atm. (853 lb. per sq. inch) and a grate area of 1.33 m² (14.2 sq. feet).

In the first instance with the original variable cone type blast pipe, the locomotive did not work satisfactorily: the fire clinkered up quickly, and had to be thrown out after running 45 km. (28 miles), so that the daily run had to be limited to this figure, and the engines and men could not be employed fully. With the « Kylchap » blast it became unnecessary to throw out the fire, the daily distance run was doubled and the load hauled was increased by more than 25 %.

In the second case, the « Kylchap » blast was the only one after many designs and in particular the double petticoat type had been tested, with which it was possible to maintain continuously the desir-

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(1) 4-6-2 locomotives working express trains on runs of 350 km. (217 miles) in four hours, and 2-8-0 locomotives working goods trains on runs of 200 km. (124 miles) in six hours.

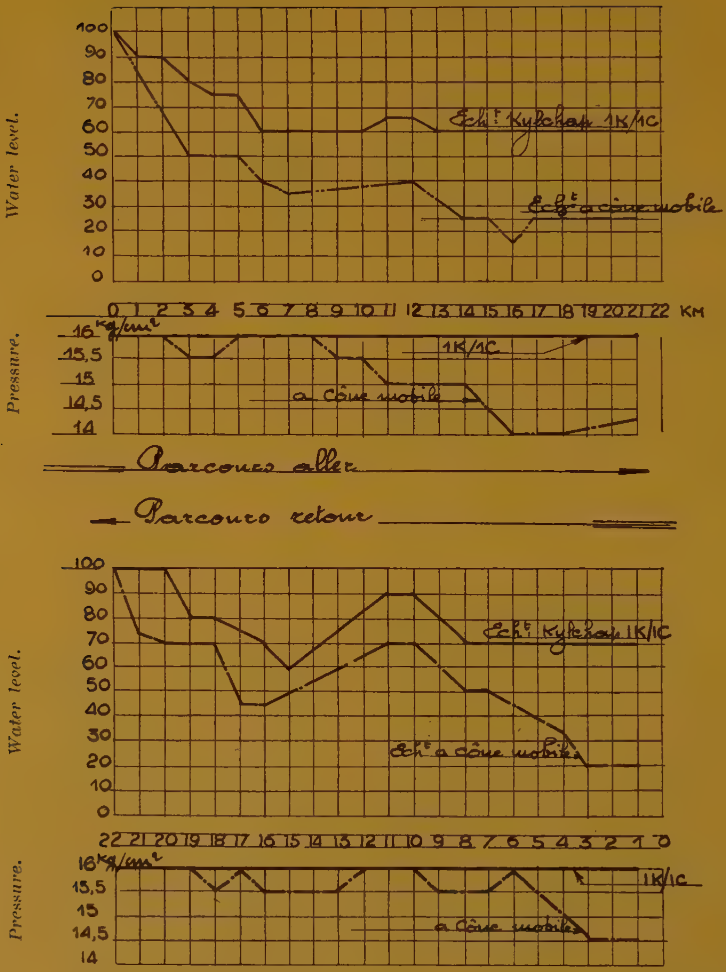

Fig. 20. — Compound articulated engine using saturated steam.

Note. — Parcours aller. = Outward journey— Parcours retour = Return journey.

ed boiler pressure of 60 kgr./cm^2 (853 lb. per sq. inch); the curves of figure 21 from records taken during the final setting of the « Kylchap » blast on the locomotive in question show the decisive advantages given from the start by this design, which made it possible to obtain quite normal steam production from the special water tube boiler fitted to this locomotive.

There are many cases in which the « Kylchap » blast has definitely cured the bad steaming typical of certain locomotives. Among such locomotives may be

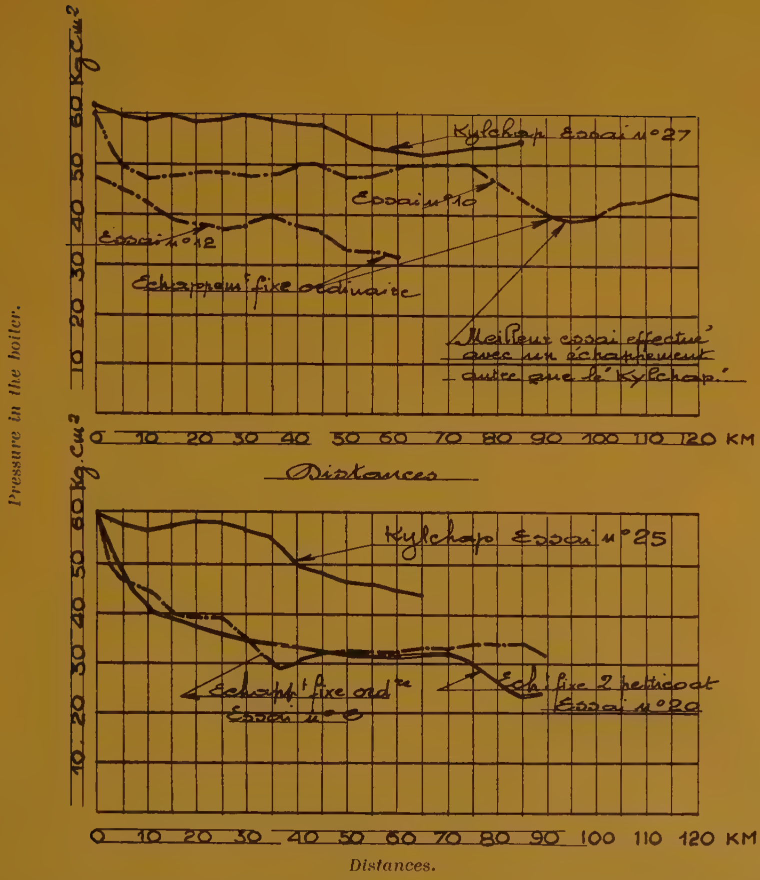

Fig. 21. — High-pressure locomotive (60 kgr./cm2 = 853 lb. per sq. inch).
Graphs showing the maintenance of pressure. Tests Nos. 6, 10, 12, 20, 25, 27.

Note. = Echappt fixe ordre = Ordinary fixed blast pipe top. — Essai = Test. — Meilleur essai... = Best test carried out with a blast other than the Kylchap.

mentioned some 4-6-0, 2-8-0, 2-8-2 tank and 4-8-0 engines frequently simple expansion, with two or four cylinders and superheated, with 2.40 to 3.10 m^2 (25.8 to 33.4 sq. feet) grate area, which gave bad results, but have given satisfactory service since their original exhaust arrangement was replaced by the «Kylchap» blast.

In the case of high-power 4-6-2, 2-8-2 and 4-8-2 type locomotives with 4 to 5 m^2 (43 to 53.8 sq. feet) grate area, it has been found easy to push the rate of combustion up to 550 to 600 kgr. per m^2 (112 to 123 lb. per sq. foot) per hour, whereas with their original design of blast it was often found difficult to work at 400 to 450 kgr. per m^2 (82 to 92 lb. per sq. foot).

It was then realised that the power of

these locomotives which had appeared to be limited by the steaming capacity of the boiler was in fact only limited by the dimensions and layout of their engines, and it has been found possible on one of the main line companies, by increasing the section af all the steam ways up to and through the ports while retaining the cylinder dimensions unchanged, to increase the power of their compound *Pacific* locomotives by about 50 %, the H. P. being raised from the normal figure of 2 000 to the exceptionally high figure of 3 000 for a locomotive with a grate area not exceeding 4.27 m² (52.7 sq. feet) (¹).

e) *Increase of power and better utilisation of the locomotives.*

The figures just given show the increase of power, in some cases quite considerable, made possible by better use of the steam capacity of the boiler as the result of fitting a well designed blast.

Such cases are not isolated, and it has frequently been found possible to increase the loads hauled by 25 to 50 % after fitting the « Kylchap » blast.

The following case may be taken as typical.

A railway owned some 2-8-2 engines, some tank with 2.77 m² (30 sq. feet) grate area, the others tender with 4.70 m² (50.6 sq. feet) grate area; the cylinders were 0.62 m. × 0.72 m. (24 3/8 in. × 28 3/8 in.) and the driving wheels 1.65 m. (5 ft. 5 in.) in diameter on both groups, all the engines being superheated simple expansion with a boiler pressure of 12 kgr./cm² (170.7 lb. per sq. inch).

The booked load at the working speed of 45 km. (28 miles) an hour on gradients of 1 in 50 was 215 tons for the tank and 275 for the tender engines.

When fitted with a variable cone type blast pipe top, the first group could only do the work with great difficulty and the fire had to be cleaned very frequently. When the « Kylchap » design was fitted, the load was limited by their adhesion alone and from the point of view of steaming it was found that 350 tons could be handled, i. e. 63 % more than with the original design of blast pipe, and 27 % more than the engines with 69 % larger grate area fitted with the variable cone type blast pipe.

When tested under constant load conditions, a locomotive of identical design as regards the mechanism but with a different boiler, with a grate area of 3.80 m² (41 sq. feet) and 14 kgr./cm² (199 lb. per sq. inch) boiler pressure, instead of 12 (170.7) when fitted with the « Kylchap » blast produced 16 000 kgr. (35 270 lb.) of steam per hour at the temperature of 370° C. (698° F.) using small Upper Silesian coal of an average calorific value of only 7 650 calories (13 770 B. T. U.), giving the very remarkable efficiency of 56 % for fuel supplied as slack, and of indifferent behaviour on the fire. Under these conditions the back pressure was only 300 gr./cm² (4.27 lb. per sq. inch) for a smoke box vacuum of 210 mm. (8.27 inches) of water.

Certain railway systems have taken advantage of the greater power obtained when the « Kylchap » blast is fitted to speed up their train timings, at the same time that they increase the loads; they have definitely increased in this way the tonne-kilometres per day as much as 150 to 200 % (daily distance run doubled and the loads increased 25 to 50 %).

Without going as far as this, which is only possible on railways where the service lends itself to such workings, increases of 20 to 40 % in the tonne-kilo-

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(¹) Cf. *Revue Générale des Chemins de fer*, July 1931, pages 18 to 67.

metres per day are of such importance that they would have justified the purchase of new locomotives had no other solution been available.

The above figures show the vital importance of improving existing locomotives to the greatest possible extent, as for example by fitting them with a good design of blast.

f) *Savings of water and fuel.*

Thanks to the reduction of back pressure it makes possible, the « Kylchap » blast gives a saving of water at equal developed horse power of 5 to 12 % according to the case.

It is of course necessary, if this saving is really to be seen, for the drivers not to take advantage of the fact that their engines are more powerful and easier to drive by handling them less efficiently; they must in addition not take advantage of the fact that the engines are freer running to wire-draw the steam at the regulator by keeping the engines in their old running notches, and thereby lose through using the steam inefficiently the saving resulting from the lower back pressure.

The saving of water so obtained already means a corresponding saving of fuel, but the saving recorded is in some cases much greater because the « Kylchap » blast gives better combustion, the evaporative rate (water evaporated, in lb. per lb. of coal) being higher.

It is not unusual in the case of locomotives, the steaming of which is defective, for this rate of evaporation to increase from 6.5 to 7 and even 7.5 lb. which gives and additional saving of fuel of some 8 to 15 %.

Finally the result of fitting the « Kylchap » blast generally has been to show in ordinary service, including all fuel used independently of the working of the engine (lighting up, standing in stations), savings of 5 to 10 %, and in certain cases even as much as 15 to 20 %.

For these savings to be recorded at their true value, however, it is essential as we have pointed out above that the new facilities should not be misused and less attention paid to economy.

When an engine is powerful, which results, in the case of a well designed blast, from keeping the pressure in the boiler well up and the back pressure against the pistons low, there is always a tendency to use this power without consideration; the acceleration is greater, the speed is not reduced so much on up gradients because the water gauge shows plenty of water, time is kept without advantage being taken of the gradients, and the trains are brought in as much in advance of the booked time as the regulations allow. This method of running is excellent and is even essential if the working is to be satisfactory, but the tonne-kilometre will cost more because each involves a greater number of kilogrammetres than the engine need develop, and finally when casually considering the time made up and the consumption per tonne-kilometre the superior efficiency of the better machine can quite well be overlooked.

It is essential, for obtaining exact results, to carry out the comparative trials with the same engine, with the same staff, with the same fuel and with the same train; at the same time the weight of water and the fuel used should be carefully measured and the work done at the drawbar should be recorded by the dynamometer car and in the cylinders by indicators.

When the dynamometer car alone is used, it must be remembered that if the trains under comparison are not equally difficult to work, which often happens in practice, the consumption of fuel and water per unit of work at the drawbar being a function of this work, the consumption curves must be drawn for both types of blast as a function of the work produced and the conclusions must be drawn from the relative positions of these curves and not from the rough averages of the figures obtained.

The conclusions drawn from a simple comparison between the average consumption (per 100 tonne-kilometres) of the locomotives of a given depot, fitted some with one design of blast and some with another, can only have any accuracy *if they represent in fact statistically accurate results.*

This condition is hardly ever met with because, in practice independently of the reasons given above, it is impossible to form with certainty two groups of locomotives of equal value; it is equally impossible to ensure that these two groups of engines work the exact same distance with identically equally difficult trains. It is also difficult to find a large enough number of locomotives to form these groups, and still more so to find the necessary sets of men of equal skill.

We may quote on this subject the example of a depot, where by changing over the firemen between the engines heading the premium lists and those last on it, the position was reversed.

The dynamometer car trial which *a priori* eliminates various factors : personel, engine (machine), fuel, tonne-kilometres, etc., is obviously the only one of any scientific value and the only one by which the value of any given arrangement can be quickly shown.

[625 .212 & 656 .284]

Axle breakages of railway vehicles and their causes,

By Reichsbahnoberrat Dr. Ing. R. KÜHNEL, Berlin.

Lecture at the meeting of the Deutsche Maschinentechnische Gesellschaft, on 19 January 1932.

(From *Glasers Annalen*, Nos. 1312 and 1313.)

From the earliest days of railway operation, the closest attention has been paid to broken axles because a broken axle still generally results in a derailment and thus endangers not only the vehicle concerned but the whole train.

Unfortunately, it is not so easy as is often assumed to say whether an axle has broken owing to defective material or owing to abnormal stress. Certain publications attribute breakages more or less exclusively to defective material (1) or, if there is no proof of such defect, the writer may refer to fatigue of material, leaving the reader to place his own interpretation on the term « fatigue ». No doubt there are cases here and there in which the material is not beyond criticism and is clearly the cause of fracture, but such cases form only a small fraction of the total number of broken axles. On the contrary, we have even found that relatively large defects are not dangerous provided that they occur in a favourable position, i. e. as nearly as possible to the centre of the cross-section of the axle. During the inflation period in Germany, many old axles were reforged for other purposes, and in many cases « pipes » were thus discovered which had given no trouble during the whole life of the axles. Figure 1 shows, for example, relatively extensive piping at the centre of an axle, but the fracture of this axle commenced from the outside.

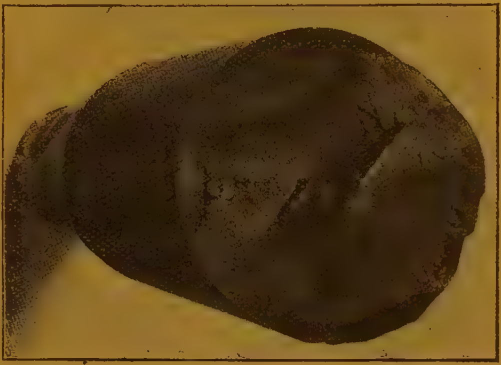

Fig. 1. — Fatigue fracture of axle begins from the outside, notwithstanding internal piping.

How do axles break ?

Ordinary fatigue fractures.

One of the basic questions which must be answered in an investigation of the causes of axle breakages is : How do axles break ? Almost invariably the breakage occurs in the form of a fatigue fracture starting from the outside (fig 2). The first beginning of the crack is difficult to detect, and only becomes visible when the surface is wiped over with coloured paraffin and subsequently chalked. If this incipient fissure is not discovered in time, it gradually extends as a fatigue fracture and as the surfaces work against each other they produce a characteristic appearance (resembling that of the annual rings in timber) from which the progress of the fracture can subsequently be observed. Unfortunately there is no indication as to whether the rings or bands correspond to periods of days, weeks, months or years, and the opinions of experts vary widely on this point. When the fatigue fracture has extended through a certain part of the axle section, complete breakage occurs. The smaller the section remaining at the time of breakage, the greater the overload it has carried and the more certainly it can generally be said, from the appearance of the fracture, that defective material was not the cause of failure. Normally the axle does not break completely until the fatigue fracture has extended through about half the section. It has sometimes been suggested (2) that the extension of the fatigue fracture may cease without complete breakage occurring, but the author is not at present prepared to accept this opinion.

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(1) See *inter alia* « Axle breakages and Spark test » : *Organ für die Fortschritte des Eisenbahnwesens*, 1924, No. 12.

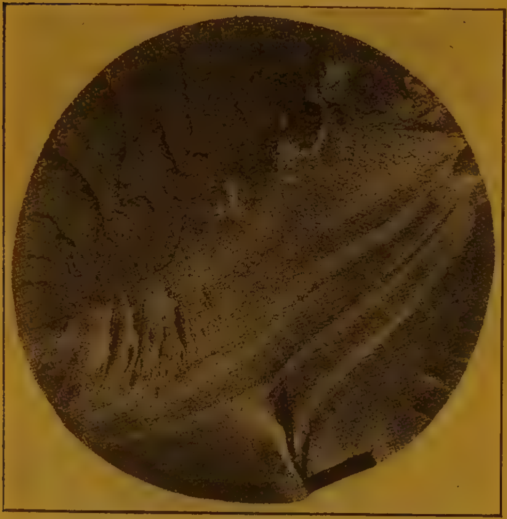

Fig. 2. — Fatigue fracture of locomotive axle.

Impact fatigue fractures.

Even if final breakage occurs when the fatigue fracture has extended across only a small part of the section, it does not always follow that the material is defective or of poor quality. Excessive stresses, such as may be caused by violent impact with wagon tippers and slipper brakes, may cause the premature fracture of axles consisting of good material. Slipper brakes and wagon tippers may, in fact, be regarded as a sort of insurance in so far as they complete the fracture of cracked axles on sidings and thus avoid accidents on the main track. Figure 3 shows such fractures in which the fatigue fracture extends over only a small part of the total section. There is, however, the danger that the same impact which completes the fracture of a cracked axle may start a crack in a sound one.

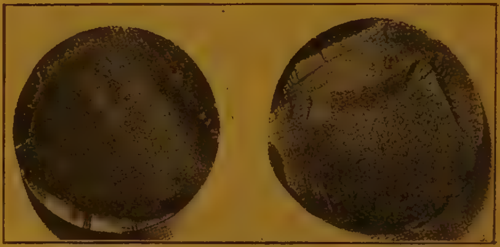

Fig. 3. — Premature fatigue fracture of axles.

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(2) *Organ für die Fortschritte des Eisenbahnwesens*, 1925, No. 19, p. 407.

Fatigue fractures due to overheating in service.

A distinctive kind of fatigue fracture is illustrated by figures 4 and 5. Three zones of different structure are visible, viz. an outer dark-coloured granular zone, and a smooth, bright zone of fatigue-fracture, with a granular fracture zone at the centre or towards the side. The three-zone fracture is not always of the concentric type. It may commence from one side resulting in a crescent shape in the transition (fatigue) zone, as shown in figure 5. The question whether the fracture commenced outside or inside in such cases has engaged our attention long ago. At first it was thought that the fracture began inside; otherwise, it was not understood why the outer zone did not show a smooth and bright fatigue-fracture grain. But we were led to admit that such cases were quite exceptional. Actually, however, the fracture commences from the outside and, as in the case of lightly stressed axles, the zone of the fatigue fracture extends so far towards the centre that the final fracture is hardly recognisable as a third zone (fig. 6).

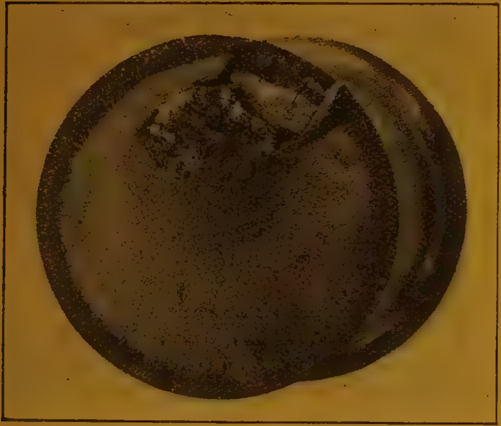


Fig. 4. — Three-zone fatigue fracture of axle due to running hot in service. Outside : concentric fissure and fatigue fracture. Centre : final fracture.

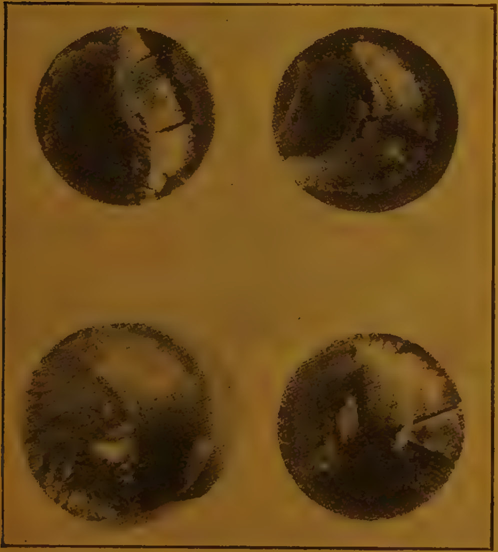


Fig. 5. — Crescent formation of three-zone fatigue fracture due to running hot.

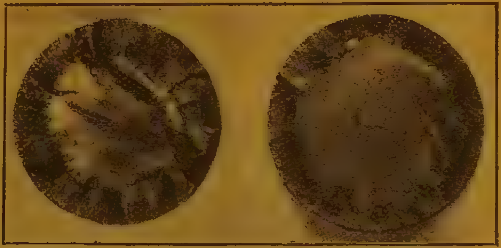


Fig. 6. — Two-zone fatigue fracture of axles due to running hot. The third zone, the zone of final fracture, is not recognizable.

Is every case these fractures are due to the axle running hot. This causes local thermal expansion of the surface of the metal and deforms the axle to some extent, the tensile strength of the material being reduced at high temperature. Figure 7 shows an axle with a number of such parallel, concentric defects. Generally, however, the cracking is not so extensive and there is formed only one fissure of varying depth. In favourable cases, the thermal effect of running hot can be clearly observed in a polished macro-section (fig . 8). Occasionally the higher magnification of a micro-section reveals traces of bearing metal which has penetrated between the grain boundaries of the steel (fig. 9). Often matters do not go so far; the overheating is detected in time, oil is supplied, and the axle continues in service. Apparently everything is in order, but if a concentric fissure has been formed, fatigue fracture commences at the bottom thereof, and complete breakage follows in due course. It is now clear why the outer zone of such a fracture is granular and remains so. The fissure is formed when the metal is hot, and the underlying layer is stretched and receives a permanent set

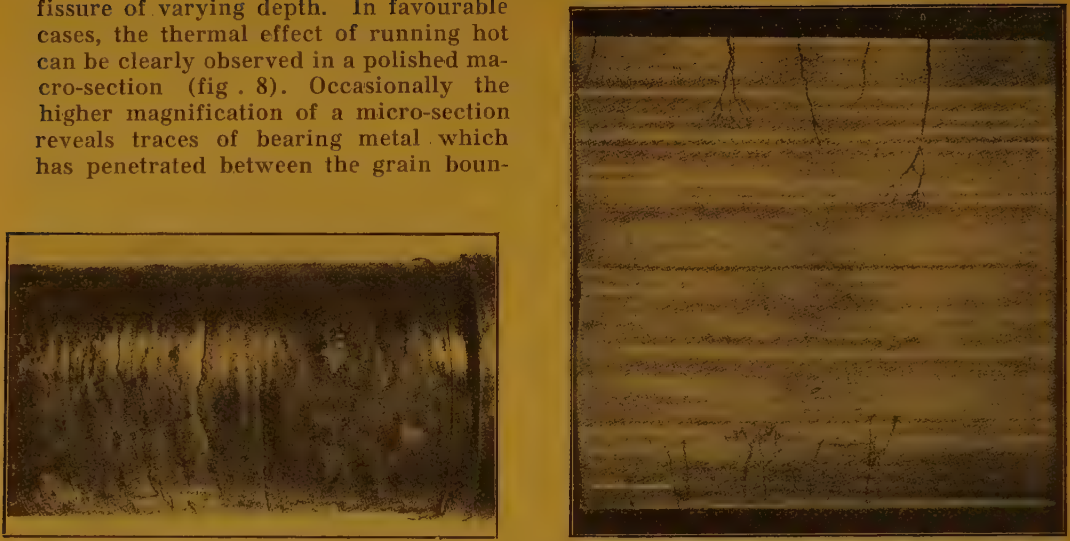

View. Etched section.

Fig. 7. — Fissures in axle journal due to running hot.

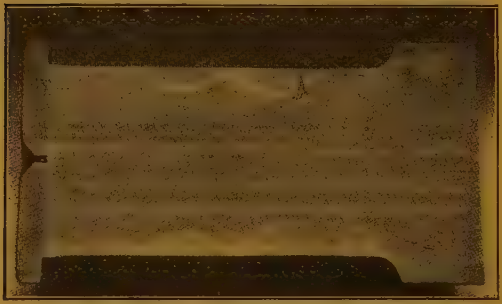


Fig. 8. — Macro-etching of an axle journal after running hot. The effect of the overheating is clearly visible.

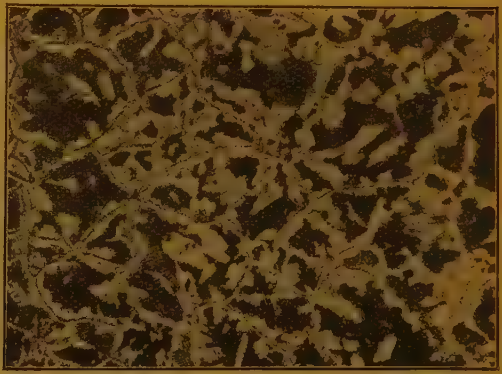


Fig. 9. — Micro-structure of axle after running hot, showing bearing metal at the grain boundaries.

which remains after the metal has cooled. The fissure therefore remains open; its walls do not rub together as the axle continues in service, and the characteristic « annual ring », appearance of the outer fracture and its granular structure is not produced. Fatigue fracture only commences at the inner boundary of this zone.

Owing to the fact that the fissure due to overheating opens, it is often detected in the workshops before the consequent fatigue fracture develops. Figure 10 shows such fissures in sections and whole axles after breakage, the central fracture being deliberately produced in these cases by testing machines or similar means. If these axles had remained in service, fatigue fractures would have developed, followed ultimately by complete breakage.

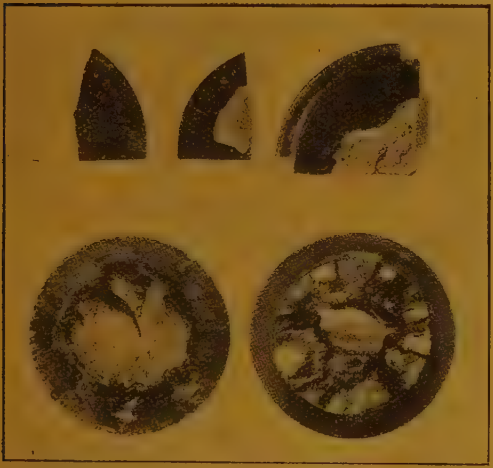


Fig. 10. — Axles or axle sections (above) showing fissures of various depths caused by running hot. The central fracture was effected deliberately in these cases.

A very interesting case is illustrated by figure 11. A carrying axle of an express locomotive, after overheating, was turned-down but not sufficiently completely to remove the fissure from which, therefore, fatigue fracture again proceeded. The defect was again detected before complete breakage occurred and the fracture was cut out as shown in the figure.

In this discussion of fatigue fractures caused by running hot, reference may be made to an investigation « Über Rotbruch des Stahls durch Lagermetalle » (On red-shortness of steel due to bearing metal), by R. SCHOTTKY, K. SCHICHTEL and R. STOLLE in *Krupp's Monthly* for May 1931. It is there shown that steel in contact with bearing metal may become red-short and, since great increase in temperature occurs locally in journals which run hot, this action should also be taken into account as a possible cause of the formation of the generaly concentric fissure.

Three-zone and two-zone fractures form so large a proportion of journal breakages that it may safely be asserted that these breakages are practically always traceable to overheating.

Results of tests on materials.

Table 1 contains the results of these tests. Before having found the above relations, subsequently confirmed in similar cases, we carried out extensive material tests, as we do on all broken axles, and thereby ascertained the static and dynamic properties as well as the chemical composition of the axles. Columns 1 and 2 give the serial numbers and the

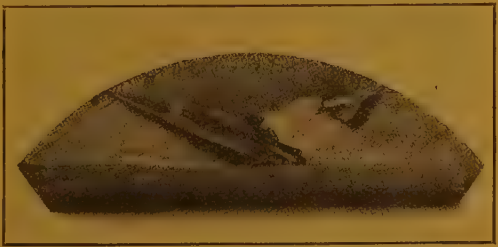


Fig. 11. — Section of axle removed to show fatigue fracture commencing again from an incompletely removed fissure caused by running hot.

TABLE 1. — **Results of te**

Serial number.	Report No.	Vehicle (1).	Elongation. %	Tensile strength, kgr./mm² (*Engl. tons per in²*).	Yield point, kgr./mm² (*Engl. tons per in²*).	Endurance streng kgr./mm² (*Engl. tons per i*
1	2	3	4	5	6	7
1	9 061	382 447	23—27	55—56 (*34.9—35.5*)	32—34 (*20.3—21.6*)	27 (*17.1*)
2	8 167	18³	18—20	57—62 (*36.2—39.3*)	29—31 (*18.4—19.7*)	23 (*14.6*)
3	7 925	39c	15—22	55—58 (*34.9—36.8*)	29—33 (*18.4—20.9*)	26 (*16.5*)
4	7 512	39c	24—26	58—60 (*36.8—38.1*)	32—34 (*20.3—21.6*)	27 (*17.1*)
5	10 319	Old 496	20—24	65 (*41.3*)	32 (*20.3*)	26 (*16.5*)
6	9 155	» 424	19—23	81—85 (*51.4—54.0*)	47—53 (*29.8—33.6*,	33 (*20.9*)
7	9 000	Goods wag.	23	60—63 (*38.1—40.0*)	... ...	... ...
8	8 807	Sleep. car	23—27	58—58 (*36.8—36.8*)	29—32 (*18.4—20.3*)	25 (*15.9*)
9	8 774	Rest. car	24—26	56—59 (*35.6—37.5*)	26—30 (*16.5—19.0*)	22 (*14.0*)
10	8 451	Goods wag.	25—26	53—54 (*33.6—34.3*)	28 (*17.8*)	25 (*15.9*)

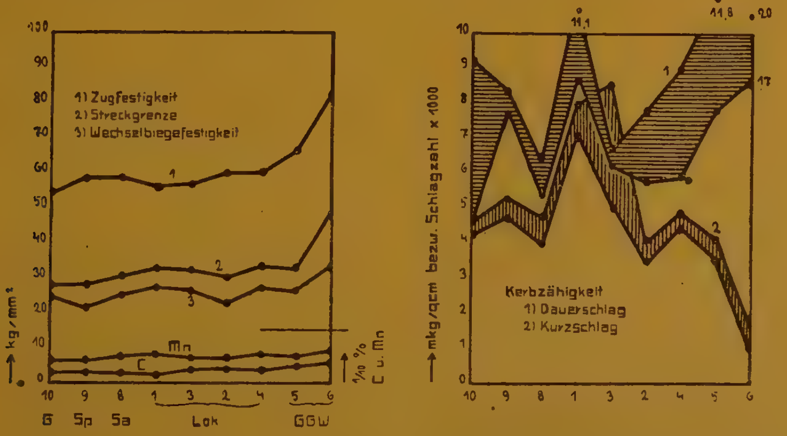
(1) Vehicles Nos. 1-4 are locomotives, Nos. 5 and 6 large-capacity goods wagons.

numbers of the test reports; column 3, particulars as to the type of vehicle, and columns 4 to 6, the elongation, tensile strength and yield point. The tensile tests were carried out by means of a 50-ton Universal machine, and on flat bars in order to be able to observe the outer zone in which the fissures begin. The fatigue strength, as given in column 7, was determined by a Schenck or Amsler repeated bending machine with 3 500 reversals of load per minute. The impact value (col. 8) was determined by means of a Charpy machine of 10 Kg.-M. (466 foot-pounds) capacity, using a bar of 5 × 10 mm. (3/16 inch × 3/8 inch) notch section and 7 cm. (2 3/4 inches) span. Column 9 contains the results of impact endurance tests on bars of 15 mm. (5/8 inch) diameter with a round notch, using a Krupp impact testing machine with a striking energy of 4.2 kgr. × 3 cm. and rotation of the bar through 180° after each blow. Column 10 shows the proportion of the fatigue fracture to the complete fracture; and the remaining columns show the chemical composition, year of delivery, and year of breakage. It should be noted that the results of the examination of the structure are not mentioned in this or later tables, and microphotographs are not reproduced, because hardly any of the many specimens examined showed any change in structure nor appreciable defects, either at the point of commencement of fracture or elsewhere. This is why the results of the examination of the structure have not been made known and photographs of the structures are not reproduced. Only the results of the mechanical tests are presented graphically in figure 12, the curves at the left referring to static loading: tensile strength, yield point and endurance strength in kgr./mm². Elongation and contraction are not shown, the values determined being all in accordance with the specifications. On the other hand, the lower left-hand curves show the carbon and manganese contents of the test pieces. In both diagrams are grouped, according to the type of vehicle, first a goods wagon axle, then axles from passenger coaches (restaurant and sleeping cars), a locomotive, and a high capacity goods wagon.

It may, perhaps, seem surprising that the endurance strength under alternating

xles after running hot.

Impact value Kg.-M./cm² ft.-lb per in²)	Impact endurance of notched bars.	Proportion of fatigue fracture.	C	Si	Mn	P	S	Year of deliv-ery.	Year of break-age.	Remarks.
8	9	10	11	12	13	14	15	16	17	18
7 9 (*336.0—368.6*)	9 600	Incipient	0.23	0.42	0.82	0.05	0.02	?	1929	Carrying axle
4 (*158.6—186 6*)	6 300	»	0.43	0.39	0.60	0.02	0.03	1919	1929	»
8.5 (*233.3—396.6*)	6 400	»	0.38	0.39	0.73	0 06	0.05	1922	1929	»
4.8 (*205.3—224.0*)	7 500	»	0 33	0 31	0.78	0.06	0.04	1924	1928	»
4.1 (*163.3—191.3*)	10 200	»	0.43	0.16	0.74	0.03	0.03	1925	1930	
1.4 (*37.3—65.3*)	18 500	»	0.53	0.24	0.88	0.01	0.02	1923	1929	
...	8 000	»	...	...	...	...	...	1928	1929	
4.7 (*182.0—219.3*)	5 900	Three-zone fracture	0.29	0.25	0 73	0.04	0.04	1927	1929	
5 3 (*219.3—247.3*)	8 000	»	0.34	0.27	0.66	0.01	0.04	1927	1929	
4.6 (*196.0—214.6*)	7 300	»	0.31	0.35	0.66	0 06	0.05	1909	1929	



—→ Type of vehicle :
GGW Large-capacity goods wagons.
G Goods wagons.
Lok Locomotives.
Sp Restaurant cars.
Sa Sleeping cars.

Static load.

—→ Type of vehicle, etc., as at the left.

Impact loading.

Fig. 12. — Mechanical properties of axles from various vehicles after running hot.

Explanation of German terms:

Zugfestigkeit = Tensile strength. — Streckgrenze = Yield point. — Wechselbiegefestigkeit = Endurance strength under alternating bending. — *Kg/mm²* = Kgr./mm². — C u. Mn = C and Mn. — *Mkg/qcm bezw. Schlagzahl* ... = Kilogrammetres per cm² and number of impacts × 1 000. — Kerbzähigkeit = Impact value. — Dauerschlag = Repeated impact. — Kurzschlag = Single impact.

bending is included with the static tests but, as will be seen from later curves, it comes naturally into this group and the parallel course of the yield point and endurance strength curves, in particular, is very evident, which is not surprising because the endurance strength under alternating bending might more correctly be termed the endurance yield point under alternating bending. The mechanical properties shown in the left-hand part of figure 12 correspond to the results of analysis and to the structure, and may be termed normal.

The right-hand portion of figure 12 shows the results of impact tests : single-impact tests ont the 10 Kg.-M. (466 foot-pounds) Charpy machine, and repeated impact tests on the Krupp (Mohr and Federhaff) machine. The scale of ordinates represents kilogrammetres per square centimetre, in the case of the lower curves, and thousands of impacts in the case of the upper curves. The whole range of variation between maximum and minimum values is indicated. Whereas the tests under static load gave no considerable variations of individual values, the impact values vary considerably, without it being possible to say with certainty whether the variations are due to differences in loading or to the material. The presentation in figure 12 is deliberately chosen in order to demonstrate the element of chance in this method of testing which, nevertheless, one would be loth to abandon in the selection of material for axles. Let us consider the strength of the notched bar under shock. The single-impact values show comparatively little scattering — but this may be an accident. Since it so happens that the arrangement of the results is almost exactly in the order of increasing tensile strength it is not surprising that the impact values decrease at the right hand side of the diagram.

The maximum at about the centre of the diagram is perhaps attributable to the increase in the manganese content. The upper curves, in the right-hand portion of figure 12, for repeated impact tests, are not always parallel to the single-impact curves but show, in the case of the axles of higher tensile strength, a marked rise, which is not fully expressed in figure 12 because the scale was halved for the last test in order to avoid increasing upwards the height of the diagram. The figures corresponding to points situated higher up are inscribed separately on the diagram. Lasche describes similar experience in his book « *Konstruktion und Material* » : « With heavy impacts, and particularly in the single-impact test, the specific impact figure of mild steel of only 45 kgr./mm^2 (28.6 Engl. tons/in^2) tensile strength is considerably greater than that of nickel-steel with over 70 kgr./mm^2 (44.4 Engl. tons/in^2) tensile strength. To the mechanical engineer, it appears at first absurd that high-tensile nickel steel should be inferior to mild steel under heavy impacts. Only testing by many light impacts reveals this superiority, and this testing by repeated impacts corresponds closely to the actual stressing of materials in machine construction. »

Special reference has been made here to these points because engineers are often inclined to rely too much on the results of single-impact tests on notched pieces and to estimate the value of materials on this basis. In the cases under consideration, axles 1 and 3 have very good single-impact values, since, as the result of many tests we are inclined to accept about 4 Kg.-M./cm^2 (219.3 ft.-lb. per sq. inch) as the normal value for such axles. Only the harder axle 6 has a lower value. Most of the repeated-impact tests (upper-right, fig. 12) show values above the normal for this material, which is about 6 000-7 000 impacts (specially favourable in the case of axle 6, in contradiction to the single-impact test). Thus, as regards their mechanical properties, structure and composition, the axles investigated are not only unobjectionable but may even be considered of superior material. The fractures of the three- or two-zone type, which nevertheless occurred, were due to operating conditions and not to defective material, so that in the future examination of cases of broken journals, the first step will not be to test the material but to seek other causes of hot running. These breakages are certainly fatigue fractures and the overheating which originated them may have occurred days or weeks earlier.

The conclusion that broken journals are almost invariably due to running hot (an exception in the case of special vehicles is considered later), brings us to the second important question which must be considered in relation to the cause of axle breakages.

Where do axles break ?

The answer usually given to this question is that breakages occur about 50 % to the right and 50 % to the left of the wheel seat. But it is rarely stated that all fractures to the right of the wheel seat (i. e. outside) are journal fractures. If the break occurs to the left of the boss (i. e. inside), it is generally close to the end of the wheel seat and is called a « boss fracture », though the term is misleading because it is not the boss that is broken but the axle inside the boss. Axles rarely break in the centre, midway between the wheels. Finally, mention must be made of crank axles, in which fractures occur at the wheel seat or at the journal collars.

Wheel seat fractures in driving and coupled axles.

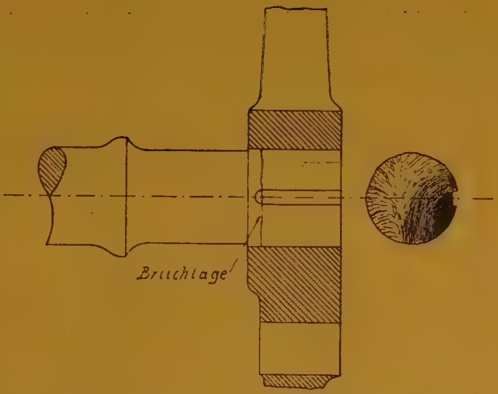


Fig. 13. — Wheel seat fracture through the keyway of a coupled axle.

Note : Bruchlage = Position of fracture.

Returning to the question of wheel seat fractures, the wheels are of course a press fit on the axles, and the driving and coupled wheels are in addition keyed on, which causes these to occur at a different point. As shown by figure 13, the break generally occurs inside the boss, near the end of the keyway. The fissure often starts at the bottom of the keyway, and then generally originates while the key is being driven if careless slotting or milling has left a torn surface anywhere. The continual alternation of load soon extends the fissure and the fatigue fracture ultimately results in complete breakage. Occasionally, the fracture may originate in the direction or the keyway, but we have only observed this once in the jack shaft of an electric locomotive (fig. 14). Usually the

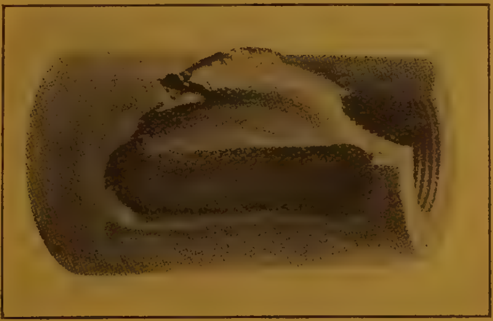


Fig. 14. — Tangential keyway fracture on the jackshaft of an electric locomotive.

TABLE 2. — **Test results for bro**

Serial number.	Report No.	Vehicle.	Elongation. °/₀	Tensile strength, kgr./mm² (*Engl. tons/in²*).	Yield point, kgr./mm² (*Engl. tons/in²*).	Endurance stre (alternating ben kgr./mm² (*Engl. tons/i*
1	2	3	4	5	6	7
1	2 585	G 88	19 --20	54—58 (*34.3—36.8*)	24—26 (*15 2—16.5*)	... ...
2	6 420	55 2177	27—30	53—55 (*33 6—34.9*)	... ...	... ...
3	6 480	55 2140	...	53 (*33.6*)	.. ...	... ...
4	3 039	?	...	57 (*36.2*)	... ...	... ...
5	11 407	55 1757	19—24	56—57 (*35.6—36.2*)	28—29 (*17.8—18.4*)	25 (*15.9*)
6	7 959	89 7252	25—26	58—59 (*36.8—37.5*)	... ...	... ..
7	8 223	55 1769	30	51—53 (*32.3—33.6*)	... ...	... ...
8	8 293	37 023	26—28	50—51 (*31.7—32 3*)	25--27 (*15.9—17.1*)	23 (*14.6*)
9	8 295	55 1813	29—30	48.5—49 (*30.8—31.1*)	26 (*16.5*)	23 (*14.6*)
10	8 362	55 1822	27—29	50—53 (*31.7—33.6*)	24—27 (*15.2—17.1*)	23 (*14.6*)
11	8 415	94 219	28—31	54—55 (*34.3—34.9*)	25—27 (*15.9—17 1*)	23 (*14.6*)
12	9 734	55 588	24—28	55 (*34.9*)	28 (*17.8*)	24 (*15.2*)
13	9 816	74 724	28—32	46—47 (*29 2—29.8*)	22—24 (*14.0—15.2*)	20 (*12.7*)
14	10 782	55 1605	-- 25	50 (*31.7*)	30 (*19.0*)	22 (*14.0*)
15	9 921	70 117	22—25	64—68 (*40.6 43.2*)	40 (*25.4*)	29 (*18.4*)

Note. — The data relating to serial Nos. 5 and 14 are from more recent tests and were inserted later, hen

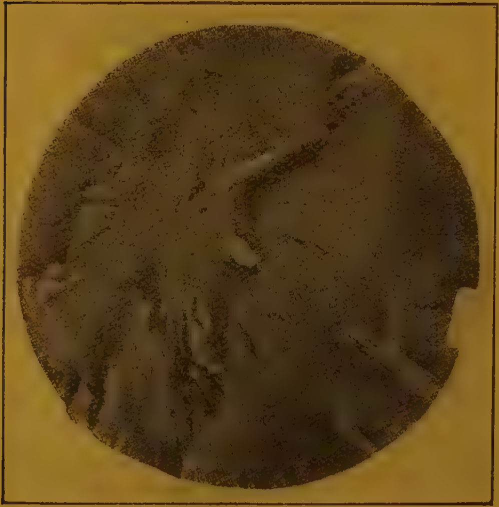


Fig. 15. — Keyway fatigue fracture.

break occurs as mentioned above, and its appearance is shown by figure 15. The commencement of the fracture can be seen at and near the keyway. It may also happen that, as the fatigue fracture proceeds, a second fatigue fracture commences in the outside fibres opposite the initial fissure (fig. 16). In the right hand fracture the small section affected, opposite the first fissure, may almost be overlooked. Often the fatigue fracture originates not in the keyway but considerably to one side thereof. The commencement of a fatigue fracture at both sides of a keyway is shown clearly in figure 17. This axle obviously broke prematurely, and owing to this, the origin of the fracture can be seen very clearly.

ng and coupled axles.

Impact value Kg.-M./cm² (*ft.-lb./in²*). 8	Impact endurance of notched bar. 9	Proportion of fatigue fracture. 10	C 11	Si 12	Mn 13	P 14	S 15	Year of delivery. 16	Year of fracture. 17	Remarks. 18
...	...	1/2	...	...	...	...	...	1906	1924	...
..	...	2/3	...	...	...	...	...	1908	1928	...
...	...	1/2	...	...	...	...	...	1908	1928	...
4.16 (*191.3—194.1*)	...	2/5	...	...	...	...	...	?	1928	...
4.1 (*70.0—191.*)	8 200	1/2	0.42	0.32	0.71	0.05	0.03	1905	1931	...
...	...	1/20	...	...	...	...	...	?	1928	Derailment.
5.9 (*121.3—275.3*)	...	3/4	...	...	..	...	...	?	1929	...
3.1 (*84.0—144.6*)	4 800	1/2	0.33	0.33	0.68	0 05	0.04	1903	1929	...
5.7 (*149.3—266.0*)	7 500	1/5	0.35	0.39	0 70	0.02	0 03	1908	1929	...
4.7 (*158.6 - 219.3*)	6 600	1/3	0.31	0.29	0 70	0.03	0.03	1908	1929	...
4.7 (*205.3—219.3*)	5 400	1/2	0.39	0 39	0.63	0.04	0.05	1907	1929	...
4.8 (*186.6—224.0*)	6 600	1/2	0 43	0.27	0.66	0.05	0.05	1904	1930	...
7.8 (*308.0—365.9*)	9 200	2/3	0.20	0.12	0.81	0.03	0.02	1906	1930	...
1.93 (*59.7—9.0*)	9 100	...(*)	0 34	0.32	0.82	0.02	0 03	1905	1931	(*) Incipient fracture.
4.7 (*140.0—219.3*)	9 400	...(*)	0.54	0.24	0.42	0.01	0.03	1915	1930	...

in columns 2 an 17 are out of sequence.

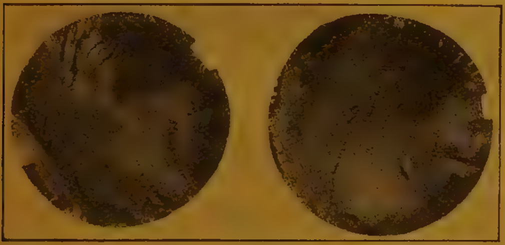


Fig. 16. — Keyway fatigue fractures.

Fatigue fracture has developed from the keyway almost to the centre. Commencement of fatigue fractures can also be seen at the opposite points, indicated by. —➤

Results of tests on materials.

In all cases of broken driving or coupled axles at the keyways, the material is always investigated to see if it is sound. Table 2 shows the results of tests car-

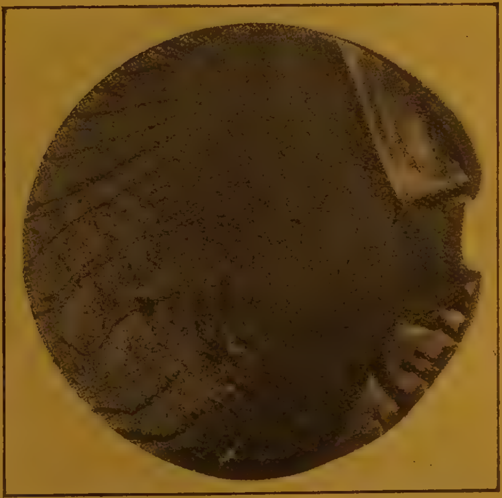
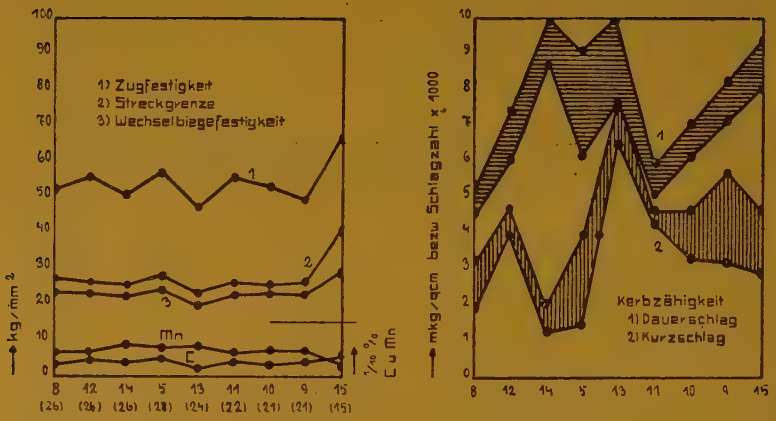


Fig. 17. — Keyway fatigue fracture. In this instance fracture commenced at both sides of the keyway.



—➤ Decreasing age (years in service shown in brackets below left-hand diagram).

Static load.

—➤ Decreasing age.

Impact loading.

Fig. 18. — Mechanical properties of broken coupled axles (keyway fractures).

Explanation of German terms:

Zugfestigkeit = Tensile strength. — Streckgrenze = Yield point. — Wechselbiegefestigkeit ≐ Endurance strength under alternating bending. — *Kg/mm*² = Kgr./mm². — C u. Mn = C and Mn. — *Mkg/qcm* bezw. Schlagzahl = Kilogrammetres per cm² and number of impacts × 1 000. — Kerbzähigkeit = Impact value. — Dauerschlag = Repeated impact. — Kurzschlag = Single impact.

ried out. The chemical analyses, where made, show carbon contents ranging from 0.20 to 0.54 %. Thus, both soft and hard axles are concerned. The variations in manganese and silicon contents are generally less marked. The injurious constituents in no case exceed the usual limits. The results of the mechanical tests are presented graphically in figure 18 (1). The left-hand diagram again contains the results of tests under static load : tensile strength, yield point and endurance strength under alternating bending. As before, the elongation figures are not plotted; they are almost invariably above 20 % and, in most cases, above 24 %. The results are arranged in order of decreasing time in service, the axles with longest service (26 years) being at the left-hand side. The values may all be regarded as normal and in conformity with specifications. Long service did not affect the properties adversely, as might have been expected. The superior properties of the youngest axle (No. 15) are not attribuable to the shorter time in service (15 years) but to the different chemical composition. The higher tensile strength did not prevent breakage.

The right-hand portion of figure 18 shows the results of the impact tests, and here again it will be seen that the impact endurance values and single-impact values rise together in some instances, e. g. axles Nos. 8 and 12, Nos. 5 and 13, and Nos. 10 and 9, whereas a high impact-endurance value corresponds to a medium single-impact value in axle No. 15, and to a low one in the case of axle No. 14. Similar variations in the relation of the two tests were observed during the examination of axles after running hot. The scattering or range of values in figure 18 (right) is again relatively favourable, but two axles, Nos. 5 and 9, show comparatively wide variations between the maximum and minimum single-impact values in each case. Similarly, there are wide ranges of variation in the impact endurance values for axles Nos. 5 and 13. The case of No. 13 shows that a high single-impact value does not prevent fatigue fracture, any more than the high impact-endurance values of Nos. 14, 13 and 15, if influences are at work which overstress the outer surface layer of the axle.

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(1) As in the preceding and subsequent charts only those axles are shown for which complete test data are available.

According to a report in *Werkzeugmaschine* (1) the English Aeronautical Research Committee has found that in shafts with keyways the ultimate strength of a carbon steel with 0.65 % C decreases by 21 %, while theoretically a value of 24 % was obtained. In the case of a material with a very low carbon content, the elastic limit decreased approximately to the same extent as in the above-mentioned carbon steel. This loss of endurance strength is taken into account by the designer. We have, however, often observed that the material round the keyway is bulged, showing that the peripheral zone is stressed to the yield point by the key. In such cases, the loss of endurance strength (alternating bending) amounts to 100 % and cannot be predetermined. It is remarkable that about half of the observed 15 fractures occurred in locomotives of the 55-series; obviously, other factors were also operative in these cases though their nature can no longer be determined. The number of such fractures, always small, has now decreased to such an extent that hardly one a year occurs. The supplementary influences, further discussed in connection with ordinary wheel seat fractures, have probably been the cause of breakage, unless they were due to overstressing set up by the key, as mentioned above.

Ordinary wheel seat fractures.
Axles of old material.

Turning now to a consideration of the breakages of ordinary axles at the wheel seat, these breakages also are fatigue fractures. The majority of wheels are simply pressed on to their axles, and are not keyed, and the fracture commences at the end of the wheel seat, almost invariably inside (fig. 19). Even in cases where the fracture apparently conmmences somewhat inside the boss it is found that the pressing-on has been done badly and the fracture coincides with the end of the effective wheel seat bearing on the axle (1).

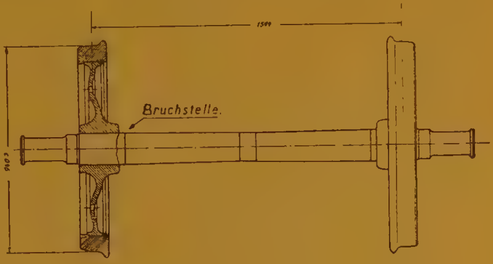

Fig. 19.
Wheel seat fracture of an ordinary axle.

Note: Bruchstelle = Position of fracture.

In itself, breakage at this point is surprising; one would naturally expect that failure would first occur in the considerably smaller journal and not at the inside of the boss where the section is much larger. This suggests that here again defective material is not the cause of fracture. The accompanying results of tests on material are divided into two groups, the first relating to axles of old manufacture (mostly before 1890), the materials of which would not be considered wholly satisfactory to-day,

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(1) No. 14. 30 July 1927, p. 301.

(1) This make also be the case where fractures of driving and coupled axles are concerned.

TABLE 3*a*. — **Test results for axles with w**

Serial number.	Report No.	Vehicle.	Elongation. %	Tensile strength, kgr./mm² (*Engl. tons/in²*).	Yield point, kgr./mm² (*Engl. tons/in²*).	Endurance stre (alternating ben kgr./mm² (*Engl. tons/i*
1	2	3	4	5	6	7
1	6 989	Goods w.	3 - 32	37—48 (*23.5 - 30.5*)	31 - 34 (*19.7—21.6*)	... ...
2	5 956	»	21—26	55—58 (*34.9—36.8*)	30 - 33 (*19.0—20.9*)	26 (*16.5*
3	8 430	Beer wag.	25—27	44—45 (*27.9—28.6*)	25—26 (*15.9—16.5*)	21 (*13.3*
4	9 060	Goods w.	15—22	59—60 (*37.5—38.1*)	30—32 (*19.0—20.3*)	23 (*14.6*
5	9 163	Lugg. van	25—27	54 - 55 (*34.3—34.9*)	29—31 (*18.4—19.7*)	24 (*15.2*
6	9 325	Goods wag.	2—28	35—45 (*22.2—28.6*)	29 (*18.4*)	26 (*16.5*
7	9 691	»	24—28	57—60 (*36.2—38.1*)	32—34 (*20.3—21.6*)	24 (*15.2*

though they proved to be capable of some 40 years' service before fracture occurred. Particulars of these axles are given in Table 3*a*, the arrangement of which corresponds to that of Table 2 (coupled axles) and need not be further explained. As regards the chemical composition of these axles, the phosphorus content is 0.1 % or higher in almost every case, indicating that the weld or Bessemer process was generally employed. Some of these test data are presented graphically in figure 20, the cases being again taken in the decreasing order of the number of years in service, and the results of static and dynamic tests being given in the left and right hand diagrams respectively. The oldest axles have relatively low tensile strength but, owing to the high phosphorus content, have a relatively high yield point and endurance strength under alternat-

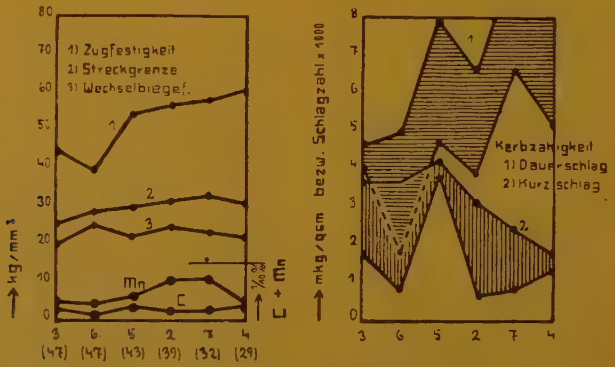


Fig. 20. — Mechanical properties of carriage axles with wheel seat fractures (old material).

Note : For explanation of German terms, see fig. 18.

fractures (old material).

mpact value Kgr.-M./cm^2 ($ft.$-$lb./in^2$).	Impact endurance of notched bar.	Proportion of fatigue fracture.	C	Si	Mn	P	S	Year of delivery.	Year of fracture.	Remarks.
8	9	10	11	12	13	14	15	16	17	18
(32.7—420.0)	...	1/10	0.14	Sp	0.48	0.10	0.05	1884	1928	
.2 (37.3—149.3)	5 300	1/5	0.28	»	1.15	0.11	0.08	1888	1927	
.7 (79.3 -172.6)	4 500	1/5	0.26	0.19	0.48	0.10	0.06	1882	1929	Shunting fracture.
.8 (65.3—84 0)	6 000	1/4	0.40	0.15	0 49	0.09	0.04	1900	»	»
.3 (186.6—200.6)	6 200	1/20	0.37	0.17	0.56	0.10	0.07	1886	»	
.7 (42.0—172.6)	3 800	1/50	0.13	Sp	0.46	0.15	0 05	1882	1829	
4 (42.0—112.0)	8 000	1/20	0.29	0.06	0.20	0.09	0.04	1898	1930	

ing bending. This explains why very old axles continue to give good service under modern conditions. The impact endurance values are not bad, though the range of variation between maxima and minima is certainly rather wide. On the other hand, the single-impact values are less satisfactory and definitely poor in the lower part of the wide range of variation. These older axles are therefore very liable to be broken by severe impacts and, for this reason, a good deal have gradually been taken out of service.

Wheel seat fractures in axles of modern material.

Table 3*b* and figure 21 show the results of tests on broken axles of more recent manufacture, the graphical presentation being again in descending order of years in service. The diagram of tests under static load shows no considerable variations. The yield point and endurance strength values are somewhat lower than before because, with otherwise similar composition, the phosphorus content is considerably lower. On the other hand, the results of the impact tests show a considerable improvement, particularly in single-impact values, with the exception of axle No. 15 in which a good impact endurance value is accompanied by low single-impact values. All these axles, however, broke in the same way, and most of the reports on the fractures state that the slipper brake or the wagon tipper was responsible for the premature complete breakage, and the cause of the first fissure. Tables 3*a* and 3*b* show that most of the wheel seat fractures of axles occur on goods wagons. Passenger coaches, sleeping cars and restaurant cars are subjected to little shunting, and wheel seat fractures of axles in such vehicles occur only in isolated cases. Some special mishap is then generally responsible for the first fissure, e. g. broken springs or heavy impact on the wheels. It is very questionable whether a further improvement in the quality of materials would prevent breakages under all the conditions of abnormal stress that may arise in service. The accompanying test data show that the broken axles include some with very good properties. If the enforcement of a further improvement in materials, say up to the level of the best qualities revealed by the present tests, did not completely eliminate wheel seat fractures, which are already few in num-

TABLE 3*b*. — **Test results for axles**

Serial number.	Report No.	Vehicle.	Elongation. °/₀	Tensile strength, kgr./mm² (*Engl. tons/in²*).	Yield point, kgr./mm² (*Engl. tons/in²*).	Endurance str (alternating be kgr./mm (*Engl. tons/*
1	2	3	4	5	6	7
1	1 430	Sleep. car.	21	56 (*35.6*)	27—30 (*17.1—19.0*)	... .
2	3 294	Goods w.	25—27	57—59 (*36.2—37.5*)	35—37 (*22.2—23.5*)	. . ..
3	5 363	»	26—27	51—53 (*32.3—33.6*)	26—27 (*16.5—17.1*)	21 (*13*
4	5 584	Rail mot. car.	25—31	55 (*34.9*)	25—26 (*15.9—16.5*)	21 (*13*
5	5 655	Goods w.	28—29	53—54 (*33.6—34.3*)	26.5 (*16.8*)	... ..
6	5 945	»	29—30	53—55 (*33.6—34.9*)	31—32 (*19.7—20.3*)	25 (*15*
7	6 955	Pass. coach.	27—34	51—52 (*32.3—33.0*)	28 (*17.8*)	22 (*14*
8	7 041	Goods w.	24—27	59—60 (*37.5—38.1*)	32—34 (*20.3—21.6*)	. . ..
9	7 114	»	...	68 (*43.2*)	... ...	... ..
10	7 200	»	28—29	52—54 (*33.0—34.3*)	26—28 (*16.5—17.8*)	22 (*14.*
11	7 809	»	28—30	50—51 (*31.7—32.3*)	28 (*17.8*)	... ..
12	8 559	»	27—29	52—54 (*33.0—34.3*)	28—30 (*17.8—19.0*)	21 (*13.*
13	10 503	Sleep. car.	28—29	52—54 (*33.0—34.3*)	28—29 (*17.8—18.4*)	22 (*14.*
14	10 835	Goods w.	27—30	50—51 (*31.7—32.3*)	28—29 (*17.8—18.4*)	... ..
15	11 591	»	29—30	52—54 (*33.0—34.3*)	25—26 (*15.9—16.5*)	21 (*13.*
16	11 793	Restᵗ car.	24—27	55—57 (*34.9—36.2*)	29—31 (*18.4—19.7*)	... ..

ber, such a step would be an economic mistake, by increasing the cost of the axles unnecessarily.

Wheel seat fractures in the axles of high-capacity goods wagons.

The study of axle breakages in high-capacity goods wagons afforded an opportunity of further examining the problem of the probable cause of wheel seat fractures. Here again, the number of such breakages was small.

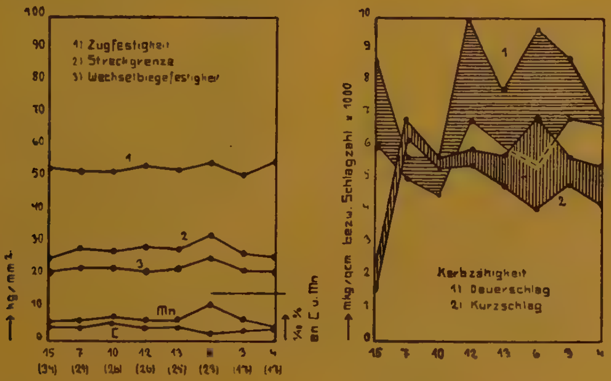
The higher axle-load and the greater mileage per time unit would lead one to expect a somewhat greater number of cracks and breakages in the axles of these vehicles, even though, on the other hand, the amount of shunting may be reduced. The wheel seat fractures do not differ here from those in other goods wagons. In most of the cases dealt with, the fissures were discovered in good time, in the early stages of the fatigue fracture. Let us again see whether the testing of the material throws any fresh light on the cause of the fractures. The data are presented in table 4 in the same arrangement as before.

The steel used (see columns 11 to 15) is a very pure manganese steel containing from 1 % to 1.3 % of manganese. Figure 22 shows, plotted in the order of increasing endurance strength under alternating bending, the results of the tests, made on material assayed in every direction.

Compared with the earlier charts, the tests under static load show considerably higher tensile strength, yield point and endurance strength, owing to the higher manganese content. The impact

el seat fractures (more recent material).

Impact value Kg.-M./cm² (*ft.-lb./in²*).	Impact endurance of notched bar.	Proportion of fatigue fracture.	C	Si	Mn	P	S	Year of delivery.	Year of fracture.	Remarks.
8	9	10	11	12	13	14	15	16	17	18
...	...	1/2	...	...	...	...	...	?	—	
..	...	...	...	...	...	...	...	?	1925	
-5.6 (*219.3—261.3*)	8 000	1/20*)	0.26	0 17	0.76	0.02	0.08	1910	1927	*) Incipient fissure detected in workshop.
-5.3 (*196.0—247.3*)	6 700	3/4	0.44	0.31	0.44	0.01	0.03	1910	1927	
...	...	1/4	...	...	...	...	...	?	1927	
6.9 (*219.3—322.0*)	7 700	1/10	0.27	0.26	1.15	0.04	0.03	1904	1927	
-6.8 (*289.2—317.3*)	5 300	1/20*)	0.40	0.20	0.05	0.04	0.03	?	1928	*) Surface fissure.
...	...	1/20*)	...	...	...	...	...	1903	1928	*) Surface fissure.
-5.8 (*140.0—270.6*)	...	1/3	...	...	...	...	...	1901	1928	
-5.6 (*247.3—261.3*)	5 000	1/10 a. 1/3*)	0.51	0.36	0.60	0.01	0.05	1902	1928	*) Fractured both sides.
...	...	1/20	...	...	...	...	...	1916	1928	Tipper.
-5.9 (*252.0—275.3*)	8 900	4/5 a. 1/10	0.41	0.23	0.64	0 04	0.03	1902	1929	Both sides.
-5.7 (*224.0—266.0*)	7 200	3/4	0.42	0.35	0.60	0 03	0.03	1904	1929	
...	...	4/5	...	...	...	...	..	?	...	
-2.3 (*70.0—107.3*)	7 200	1/10*)	0.46	0.24	0.62	0 05	0.04	?	1930	*) Wagon tipping.
-4.1 (*84 0—191.3*)	...	4/5	...	...	...	...	...	?	1930	



—→ Decreasing age.
Static load.

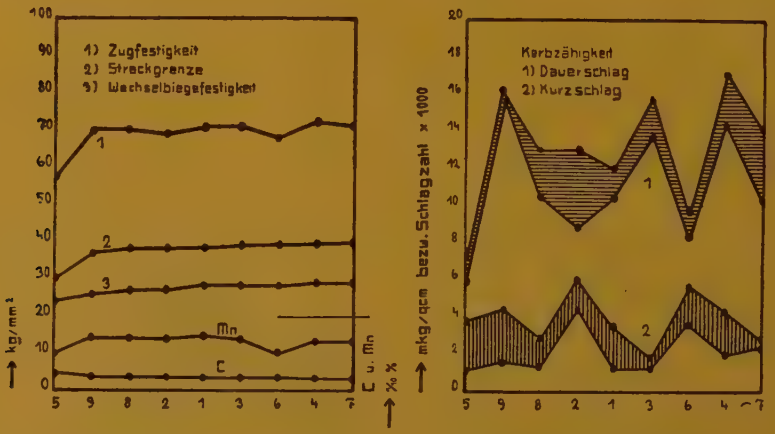
—→ Decreasing age.
Dynamic loading.

Fig. 21. — Mechanical properties of carriage axles with wheel seat fractures (new rolling stock).

Note : For explanation of German terms, see fig. 18.

TABLE 4. — **Test results for axles of high-capac**

Serial number.	Report No.	Vehicle.	Elongation. °/₀	Tensile strength, kgr./m/m² (*Engl. :ons/in²*).	Yield point, kgr /mm² (*Engl. tons/in²*).	Endurance stren (alternating bend kgr.m/m² (*Engl. tons/in*
1	2	3	4	5	6	7
1	9 032	Old. 730	19—21	70—71 (*44.4—45.1*)	38—39 (*24.1—24.8*)	28 (*17.8*
2	10 336	» 721	23	67—70 (*42.5—44.4*)	36—39 (*22.8—24.8*)	27 (*17.1*
3	10 813	» 711	20—21	70—71 (*44.4—45.1*)	39 (*24.8*)	28 (*17.8*
4	10 813	» 711	18—21	71—73 (*45.1—46.3*)	39—40 (*24.8—25.4*)	29 (*18.4*
5	10 899	» 546	25—26	57—58 (*36.2—36.8*)	29—31 (*18.4—19.7*)	24 (*15.2*
6	11 292	» 505	23—24	67—68 (*42.5—43.2*)	39 (*24.8*)	28 (*17.8*
7	11 299	» 713	23	71 (*45.1*)	40 (*25.4*)	29 (*18.4*
8	11 819	» 660	21—22	70.5 (*44.7*)	38 (*24.1*)	27 (*17.1*
9	11 833	» 561	19—22	70 (*44.4*)	37 (*23.5*)	26 (*16.5*



—➤ Increasing endurance strength.
Static load.

—➤ Increasing endurance strength.
Impact loading.

Fig. 22. — Wheel seat fracture in axles of high-capacity goods wagons.

Note : For explanation of German terms, see fig. 18.

endurance values are considerably increased (the vertical scale of the right-hand diagram in figure 22 is half that of the earlier charts), the average being about 12 000 impacts of 4.2 kgr. × 3 cm. for specimens with rounded notch. On the other hand, the vulnerability to single impacts is increased, and the energy that can be absorbed averages only 2 to 4 Kg.-M./cm² (109.65 to 219.3 foot-pounds

wagons with wheel seat fractures.

mpact value Kg.-M./cm^2 ft.-lb./in^2). 8	Impact endurance of notched bar. 9	Proportion of fatigue fracture. 10	C 11	Si 12	Mn 13	P 14	S 15	Year of delivery. 16	Year of fracture. 17	Remarks. 18
.3 (*58.3—153.9*)	11 200	1/50	0.32	0.27	1.52	0.03	0.02	1928	1929	
.1 (*196.0—284.6*)	10 000	1|2 a. 1|5*)	0.02	0.32	1.35	0.01	0.02	?	1930	*) Broken on both sides at the wheel seat.
8 (*60.6—84.0*)	14 500**)	1/10	0.35	0.38	1.35	0.02	0.02	?	1930	**) 5 000 with sharp notch.
.3 (*93.2-200.6*)	15 500	1/10	0.34	0.36	1.32	0.02	0.02	?	1930	
.8 (*60.6—177.3*)	6 100	Start. fiss.	0.45	0.35	1.02	0.02	0.02	?	1930	Also journal fissure.
.7 (*172.6—266.0*)	8 600	1/4	0.36	0.40	0.97	0.03	0.04	1927	1931	Double piping.
.8 (*112.0—130.6*)	11 800	***)	0.36	0.40	1.32	0.03	0.02	?	1930	***) Fracture crushed.
.8 (*60.6—130.6*)	11 600	4/10	0.35	0.16	1.40	0.02	0.02	1929	1931	
.4 (*70.0—205.3*)	15 800	1/4	0.31	0.31	1.42	0.01	0.02	?	1931	

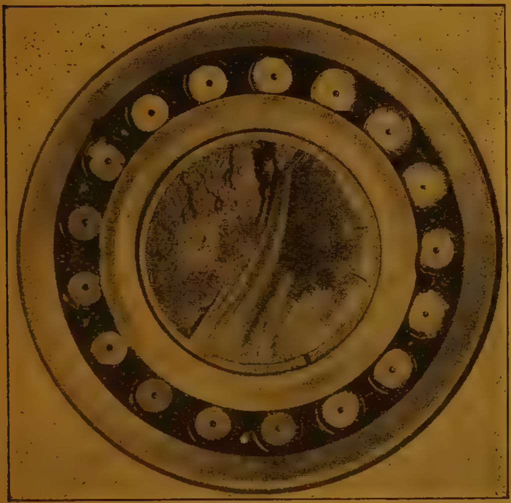


Fig. 23 — Fatigue fracture in journal of high-capacity goods wagon (outer ring of bearing still in place).

per sq. inch.), though there are axles (Nos. 2 and 6) with single-impact values of from 4 to 6 Kg.-M./cm^2 (219.3 to 328.95 foot-pounds per sq. inch). The material may thus be said to be unexceptionable. Nevertheless, fissures and fractures occurred in these axles, always commencing at the wheel seat flange. Some supplementary stresses must occur, which endanger the material.

Journal fractures in high-capacity goods wagons.

It is peculiar that the same kind of fracture occurs in the journals of high capacity goods wagons fitted with roller bearing axle boxes, at the taper clamping sleeve. With few exceptions, the journal fractures of these wagons are not due to running hot (as in the case of other vehicles), but are related in cause to wheel seat fractures. Figure 23 shows such a fatigue fracture with the taper clamping sleeve of the bearing still in position, while figure 24 gives a side view of a broken journal with the clamping sleeve removed. The tearing action of the bearing sleeve on the surface of the axle is clearly visible.

Tests were again made on axles with

TABLE 5. — **Test results for axles of high-capa**

Serial number. 1	Report No. 2	Vehicle. 3	Elongation. % 4	Tensile strength, kgr./mm² (*Engl. tons/in²*). 5	Yield point, kgr./mm² (*Engl. tons/in²*). 6	Endurance stre (alternating ben kgr./mm² (*Engl. tons/i* 7
1	8 644	Old. 568	24—25	59—60 (*37.5—38.1*)	29—31 (*18.4—19.7*)	24 (*15.*
2	10 484	» 539	27	58—59 (*36.8—37.5*)	32 (*20.3*)	26 (*16.*
3	10 502	» 578	23—24	58—61 (*36.8—38.7*)	... ...	... ..
4	10 758	» 538	25—27	59—61 (*37.5—38.7*)	29—30 (*18.4—19.0*)	25 (*15.*
5	10 665	» 708	15	67—68 (*42.5—43.2*)	36—39 (*22.8—24.8*)	31 (*19.*
6	10 789	» 558	30	55 - 57 (*34.9 - 36.2*)	33 35 (*20.9—22.2*)	... .
7	10 809	» 557	21	61—62 (*38.7—39.3*)	... ...	... ..
8	10 871	» 664	24—26	69—70 (*43.8—44.4*)	38—39 (*24.1—24.8*)	30 (*19.*
9	10 872	» 686	26	66 (*41.9*)	35 (*22.2*)	28 (*17.*
10	10 883	» 671	23—24	66—67 (*41.9—42.5*)	38—39 (*24.1—24.8*)	... ..
11	10 898	» 732	20—21	67—68 (*42.5—43.2*)	35—36 (*22.2—22.9*)	27 (*17.*
12	10 899	» 546	25—26	57—58 (*36.2—36.8*)	29—31 (*18.4—19.7*)	24 (*15.*
13	10 974	» 664	18	61 (*38.7*)	24 (*15.2*)	... ..
14	10 976	» 740	21—22	67—68 (*42.5—43.2*)	36—38 (*22.8—24.1*)	29 (*18.*
15	11 008	Test bed.	27—28	58 (*36.8*)	33—34 (*20.9—21.6*)	27 (*17.*
16	11 915	Old. 586	21—22	64—65 (*40.6—41.3*)	31—32 (*19.7—20.3*)	26 (*16.*

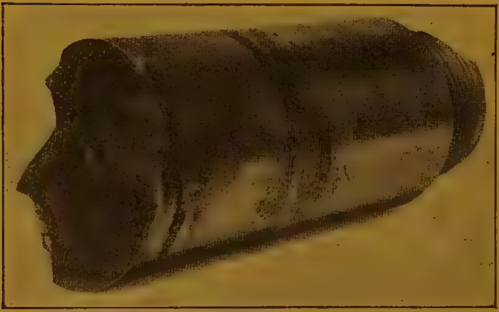


Fig. 24. — Side view of broken journal of high-capacity goods wagon. The pressure zone of the bearing shell at the commencement of the fracture is clearly visible.

this type of fracture to ascertain whether defective material was responsible. Table 5 contains data regarding the mechanical properties and chemical composition (¹).

The results of static and dynamic tests on some of these axles are shown graphically in figure 25, arranged in ascending order of endurance strength under alternating bending. The tensile strength lies between 60 and 70 kgr./mm² (38.1 and 44.4 Engl. tons/sq. in.), the yield point between 30 and 40 kgr./mm² (19.0 and 25.4 Engl. tons/sq. in.), and the endurance strength between 25 and 30 kgr./mm² (15.9 and 19.0 Engl. tons/sq. in.). The single impact test values average about 4 Kg.-M./cm² (219.3 ft.-lb./sq. in.), but include some considerably lower figures, as well as some very good values (axles No. 2 and

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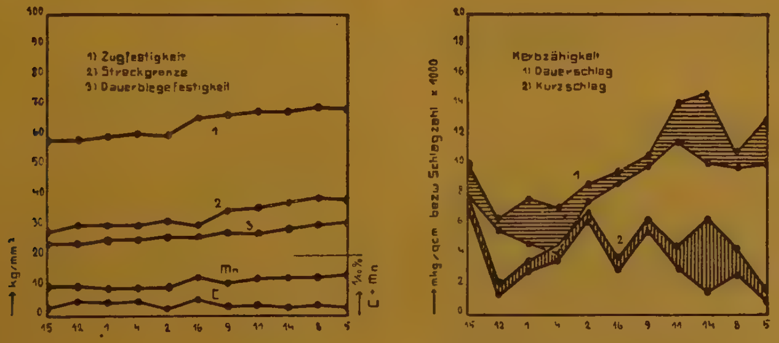
(¹) Axle No. 15 was broken during a laboratory test.

s wagons with journal fractures.

Impact value Kg.-M./cm^2 (*ft.-lb./in^2*).	Impact endurance of notched bar.	Proportion of fatigue fracture.	C	Si	Mn	P	S	Year of delivery.	Year of fracture.	Remarks.
8	9	10	11	12	13	14	15	16	17	18
3.5 (*140.0—163.3*)	6 200	3/4	0.42	0.23	0.95	0.02	0.03	1912	1929	
7.0 (*294.0—327.0*)	8 100	4/5	0.27	0 27	0.96	0 03	0 03	1926	1930	
3.3 (*79.3—154.0*)	10 400	3/4	0.36	0.25	0.75	0.03	0 03	1927	1930	
4.6 (*168.0—214.6*)	6 000	...	0.49	0.36	0.95	0.01	0.03	1926	1930	
1.76 (*46.7—82.1*)	11 300	3/4	0.32	0.30	1.35	0 03	0.01	1928	1930	
9 (*294.0—420.0*)	...	...	...	...	...	...	...	?	1930	
3.6 (*130.6 - 168.0*)	...	...	...	...	...	...	...	1927	1930	
4.6 (*126 0—-214.6*)	10 700	Surface crack.	0 36	0.32	1.28	0.03	0.02	?	1930	
6.4 (*261.3--298.6*)	10 100	»	0.31	0.30	1.10	0.01	0.02	?	1930	
6.4 (*275.3—298.6*)	. .	1/2	0.37	0 35	1.37	0.02	0 02	?	1930	
4 5 (*144.6—210.0*)	13 300	Surface crack.	0.35	0.33	1.24	0.01	0.02	?	1930	
3.8 (*60 6—177.3*)	6 100	»	0.45	0.35	1.02	0.02	0.02	?	1930	Also wheel seat crack.
...	...	»	...	...	...	...	...	?	1930	
6.4 ([*84.0*] - *298.6*)	12 800	3/4	0.32	0.37	1.30	0.02	0 02	?	1930	
7.6 (*340.6--354.6*)	9 100	...	0.28	0.33	1.02	0.02	0.02	?	...	Roller bearing with retaining ring.
3.6 (*135.3—168.0*)	9 100	Surface crack.	0.51	0.36	1.08	0.03	0.02	?	1930	



→ Increasing endurance strength.

Static load.

→ Increasing endurance strength.

Impact loading.

Fig. 25. — Mechanical properties of broken journals from high-capacity goods wagons.

Note : For explanation of German terms, see fig. 18.

9). The range of variation is small in most cases. The impact endurance values also show a moderate range of variation, with very high values for axles Nos. 5, 8, 9, 11 and 14. Thus, here again, the materials of the axles investigated are substantially satisfactory. Also, these fractures and the wheel seat fractures showed no defective structure at the commencement of the break, though the incipient fissures were often detected and laid bare as in figure 26. This agrees with the results of earlier investigations in Germany, whereas publications abroad often refer to a change in structure at the initial fissure. As far as the author can ascertain, however, these results relate to fractures produced solely by laboratory trials, and not to axles or other components broken in service. Our investigations all show that the cleavage has occurred gradually without the crystals adjoining the fracture being appreciably distorted.

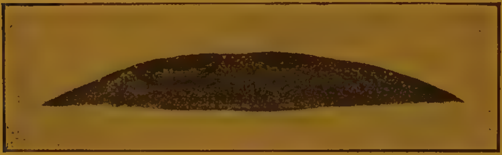


Fig. 26. — Incipient fatigue fracture in an axle.

Supplementary factors which may contribute to wheel seat fractures.

In the author's opinion, there is no occasion to suspect any mysterious change in material as the cause of the initial fissure in wheel seat fractures of all kinds, but we must seek the contributory causes which have stressed the surface, at the point of commencement of the fracture, to such an extent as to result in gradual cleavage. Two causes, in particular, have to be considered, viz. the pressure of the shrunk-on wheel centre or of the taper clamping sleeve and the notch-effect of the change of section from the wheel seat to the journal and to the axle. There are other possible causes, e. g. heavy blows and hence excessive tangential surface stress during erection, but these are not further considered here.

As regards the compression effect, Dr.-Ing. A. Müller, in a paper on « Fatigue of materials and bending stresses in driving shafts » (*Maschinenbau*, 1930, No. 19, p. 640), estimates that the endurance strength of transmission shafts under alternating bending is reduced by at least 30 % when fitted with discs.

The same question was dealt with experimentally, at about the same time, in a paper « The influence of surface-damage on endurance strength under alternating bending » (*Metallwirtschaft*, 1929, No. 4, p. 77). In this instance, W. Zander investigated the effect of supplementary compressive loading applied to a test bar by two opposite ring-pressure pieces of 5 mm. (3/16 inch) bearing breadth. This ring loading has a very marked effect on the endurance of the bar, lowering it 51 % in the case of WKS-steel. Whereas the normal endurance strength was 52.5 kgr./mm^2 (33.3 Engl. tons per sq. in.), the bar broke at 25.6 kgr./mm^2 (16.2 Engl. tons per sq. in.) when the ring was applied. The fracture occurred at the outer edge of the ring next to the centre of the test piece, i. e. on the side of greater bending moment, i. e. again to the inside as in the case of wheel seat fractures.

Information has also become available quite recently regarding the notch-effect of the wheel boss, which apparently predominates over the pressure effect. Round bars for alternating bending tests were provided at the centre with a collar resembling a wheel boss, and then tested in the Schenck alternating bending machine. Dr.-Ing. W. Schneider reports such tests in *Stahl und Eisen*, No. 10, p. 825. The collars employed were rounded off to 3 and 1 mm. (1/8 inch and 3/64 inch), but were only 1/3 larger than the diameter of the bar, and therefore did not produce so marked a reduction in endurance strength as was observed by Ludwik (*Metallwirtschaft*, 1931, No. 37, p. 705). Ludwik used collars of thickness 2 *d*, with only 0.5 mm. rounding and found, with steel 48 (corresponding approximately to our axle steel), that, under the effect of the collar, the endurance bending strength of the polished bar was reduced from 27 to 15 kgr./mm² (17.1 to 9.5 Engl. tons per sq. in.). In the case of a hard, heat-treated chromium-nickel steel, the corresponding reduction was from 54 to 26 kgr./mm² (from 34.3 to 16.5 Engl. tons per sq. in.).

Though all these tests may approximate to the loading of an axle by the wheel boss, it is questionable whether they imitate the exact conditions existing in railway axles. We attempted therefore to obtain yet greater similarity between experimental and service conditions. Of the testing machines at our disposal only the Amsler rotating bar fatigue machine (fig. 27) appeared to be suitable for carrying out tests under approximately the conditions of service. Figure 28 shows, at the top, an ordinary test bar No. 1 for this machine. For the purpose of the photograph, the bar is ground at the centre, where it is supported and driven in the testing machine. Loads, not necessarily equal, on the left and right, are hung on roller bearings at the outer ends of the rod. For the material chosen, with a tensile strength of 50-60 kgr./mm² (31.7 to 38.1 Engl. tons per sq. in.), the endurance strength under alternating bending was 23 kgr./mm² (14.6 Engl. tons per sq in.) as noted right and left on the centre of the bar. The next test bar, No. 4, is of the same dimensions but with a pressed-on ring. The central portion of the bar projects somewhat from the ring before being reduced to the diameter of the actual test bar. As thus arranged, the pressed-on ring does not endanger the material, the endurance strength of which is even somewhat increased as shown by the inscribed figures. In test bar No. 6, the central portion is not extended; the reduction of the bar commences exactly at the end of the ring, and the endurance strength is somewhat reduced, to 22 kgr./

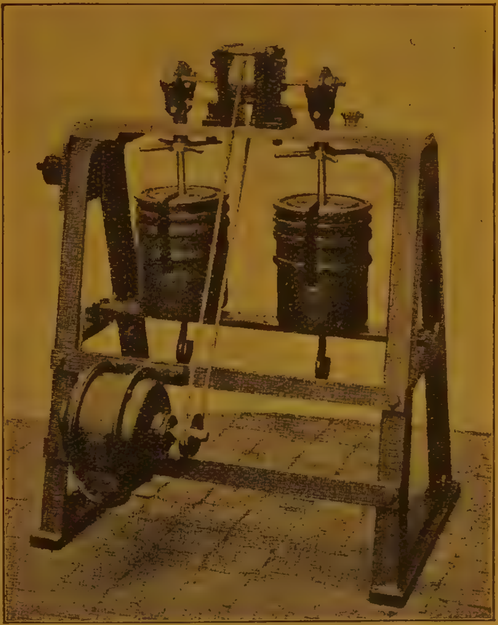


Fig. 27. — Amsler fatigue testing machine (alternating bending).

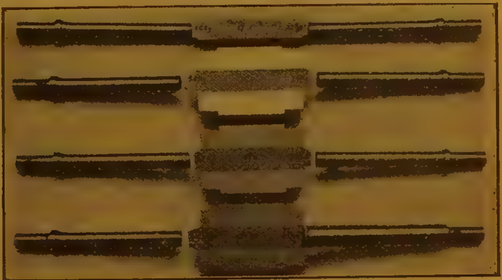


Fig. 28. — Fatigue test specimen bars with and without pressed-on boss.

mm² (14.0 Engl. tons per sq. in.). Nevertheless, the effect of the ring still cannot be said to be serious. A very different state of affairs exists, however, in the next test bar, No. 11, which is a direct imitation of the form of an axle. The left-hand portion corresponds to the journal, and the right-hand portion of full cross section corresponds to the body of the axle. The endurance strength of the journal portion of the bar is 21 kgr./mm² (13.3 Engl. tons per sq. in.), showing a distinct but not too serious reduction due to the ring; but the right-hand portion of the bar broke at the shoulder of the ring at only 13-15 kgr./mm² (8.2 to 9.5 Engl. tons per sq. in.). In other words, the endurance strength is almost halved. The specimen with the most unfavourable value, 13 kgr./mm² (8.2 Engl. tons per sq. in.), is reproduced in figure 28. From this, it appears that the notch effect of the ring far outweighs its compression effect.

In order to settle this point definitely, yet another test was carried out. Test bars imitating the journal, boss and axle body were turned from the solid; the form and dimensions were the same as before, but the effect due to the shrinking on of the boss was completely eliminated. The results of two tests were again in agreement; left 22 kgr./mm² (14.0 Engl. tons per sq. in.), right 13 kgr./mm² (8.2 Engl. tons per sq. in.) (fig. 29). In order to confirm that the difference was not due to any cause in the testing machine, a test was carried out with both sides of the specimen of the larger form; the result was then 13 kgr./mm² (8.2 Engl. tons per sq. in.) on both sides. Finally, this test was repeated with a small rounding-off at the change in section of bar No. 4. The result was 17 kgr./mm² (10.8 Engl. tons per sq. in.) or again considerably more favourable. The left-hand side of the boss failed by running hot, and was not taken into account.

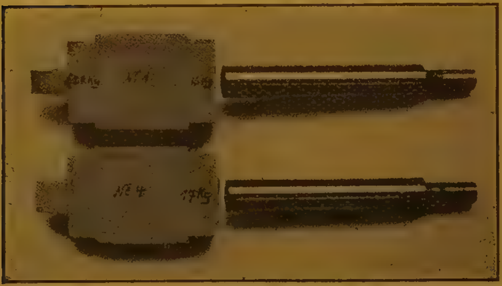


Fig. 29. — Fatigue test bars machined from the solid (boss and bar in one piece).

The notch effect of the boss or collar transition is thus very dangerous and is no doubt the principal supplementary factor facilitating the occurrence of wheel seat fractures. In future, the axle must be well rounded at the wheel seat shoulder.

If the axle is carried in roller bearings, as in high-capacity goods wagons and other vehicles, there is, in effect, a new boss applied to the journal (see B, fig 30), and this endangers the surface of the journal by its collar-effect. The danger may be increased by the hardness of the retaining ring and various constructional details which need not be

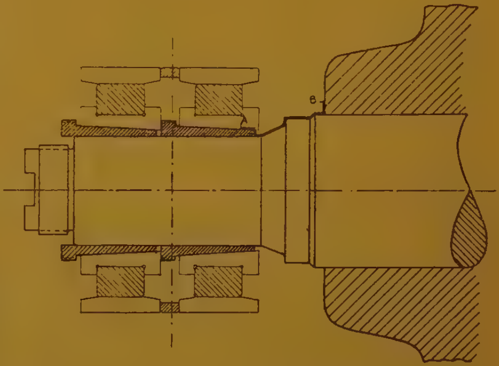


Fig. 30 — Axle journal with retaining ring and roller bearing.

further discussed at present. Quite a number of constructional innovations have been developed with a view to preventing, as far as possible, the breakage of axles from this cause.

Before leaving these considerations, something must be said concerning the so-called « Edelrost » or efflorescent rust which affects axles at the end of the wheel seat where fracture occurs. Broken axles, as well as our test specimens (excepting those turned from the solid), showed a reddish-brown coating of rust at the inner end of the nave at the point of fracture of the axle. Its origin is obvious. The axle endeavours to escape from the dangerous notch-effect of the boss, and to take up a more favourable position with regard to the direction of the existing forces. It pulls at the boss, which yields to some extent at the rim; there is thus a « working » of the axle against the edge of the boss, which must already affect the durability adversely. Fine particles are rubbed off, and they oxidise rapidly owing to their fineness. Other explanations have been advanced to account for the formation of the coating of rust (or the corresponding black coating which forms in the case of light metals), but the author does not propose here to discuss these rather bold theories. The rust does not appear on the journal side, where the axle is rounded off at the change of section and the stresses better distributed.

From the above, it will be seen that the rusting is a secondary action and it is hardly justifiable to regard it as a special supplementary factor contributing to the reduction of the endurance strength. On the other hand, moisture and fatty acid residues (from the oil) may collect where the « Edelrost » is found, thus setting up corrosion as a contributory influence on boss fracture. It may even be the sole cause of axle breakages in some cases, but such breakages occur between the wheel seats and more towards the centre of the axle.

Breakage at the middle of axles : corrosion as a cause of fracture.

Observations on such fractures have been made in England. The axles in question were exposed to the flushing water from W. C.'s in passenger coaches, and broke prematurely. These observations induced us to investigate the reduction of endurance strength caused by water sprinkling. A detailed account of the English results and our own experiments is given in *Maschinenbau*, 1931, No. 22. The Schenk rotating bar fatigue machine was used for our tests, the experimental equipment being as shown in figure 31. Water was dropped on the centre of the test bar (¹) at the rate of about 1 drop per second from a height

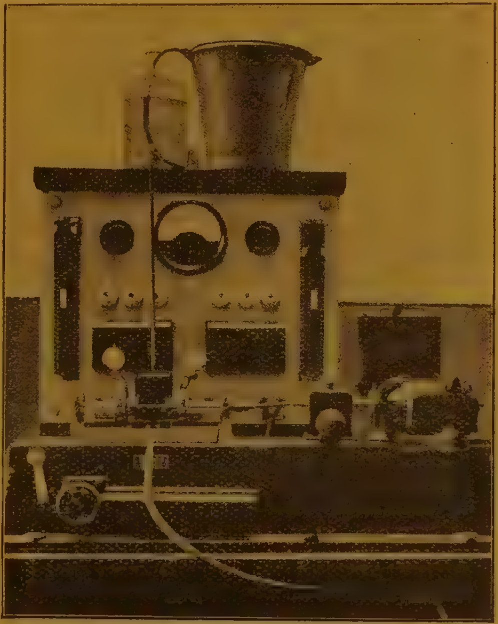


Fig. 31. — Corrosion test with water sprinkling.

(¹) The splash guard is open in figure 31 to show the test bar.

TABLE 6. — **Fatigue tests (alternating bending) with water-sprinkling.**

Serial number.	Material.	Tensile strength, kgr./mm² (*Engl. tons/in²*).	Yield point, kgr./mm² (*Engl. tons/in²*).	Endurance strength (alternating (bending), without sprinkling kgr./mm² (*Engl. tons/in²*).	with sprinkling kgr./mm² (*Engl. tons/in²*).	Report No.
1	Wrought iron axle	31—34 (*19.7—21.6*)	16—19 (*10.1—12.1*)	13 (*8.2*)	9 (*5.7*)	9 638
2	Eccentric rod	37—40 (*23.5—25.4*)	25—28 (*15.9—17.8*)	20 (*12.7*)	12 (*7.6*)	8 904
3	Jz I	38—39 (*24.1—24.8*)	22—24 (*14.0—15.2*)	20 (*12.7*)	12 (*7.6*)	6 732
4	Jz IV.	46—47 (*29.2—29.8*)	30—31 (*19.0—19.7*)	23 (*14.6*)	12 (*7.6*)	6 732
5	Crank axle	61—62 (*38.7—39.3*)	26 (*16.5*)	23 (*14.6*)	11 (*7.0*)	8 692
6	High-capacity goods wagon axle Old. 538.	59—61 (*37.5—38.7*)	28—30 (*17.8—19.0*)	25 (*15.9*)	11 (*7.0*)	10 758
7	Ditto Old. 496	65 (*41.3*)	... ...	24 (*15.2*)	12 (*7.6*)	10 319
8*a*	Ditto Old. 666-I.	70—74 (*44.4—47.0*)	39 (*24.8*)	28 (*17.8*)	12 (*7.6*)	10 319
8*b*	Ditto Old. 666-II	70—74 (*44.4—47.0*)	39 (*24.8*)	28 (*17.8*)	12 (*7.6*)	10 665
9	Ditto Old. 424	81—85 (*51.4—54.0*)	47—53 (*29.8—33.6*)	33 (*20.9*)	13 (*8.2*)	9 155
10	Ditto Old. 666 (Coated with red lead)	70—74 (*44.4—47.0*)	39 (*24.8*)	28 (*17.8*)	28 (*17.8*)	10 665

of 1 cm. (3/8 inch). Table 6 shows the results obtained, the frequency of alternation of the load being 3 500 per minute. It will be seen that, as in the case of the notch-effect of the boss, the endurance strength is reduced by about 50 %. The dripping actually produces a notch-effect, corrosion fissures being formed as shown in figure 32.

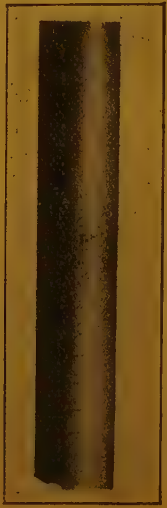


Fig. 32. — Corroded fatigue test bar, showing surface fissures.

Hitherto, we have only received one case for examination in which corrosion was the immediate cause of the fatigue fracture, as in the English cases. The axle in question broke almost exactly in the middle, far away from both wheel seats. Water dripping from the wagon (a beer wagon) on the axle caused deep corrosion fissures as shown in figure 33. The breakage of this axle caused the derailment of three wagons as the goods train entered a station. Similar corrosion fractures may occur in the case of wagons used to carry acids.

Welding as a cause of breakage.

A second case of breakage at the centre of a goods wagon axle was due to building up by welding (see fig. 34). The material of the axle was normal.

This raises the question whether welding exerts a detrimental effect on the endurance of the axle material, comparable with the effects found as regards the wheel boss and corrosion.

In the case considered this is so (¹).

(¹) Welding axles has been prohibited by the Reichsbahn for some time.

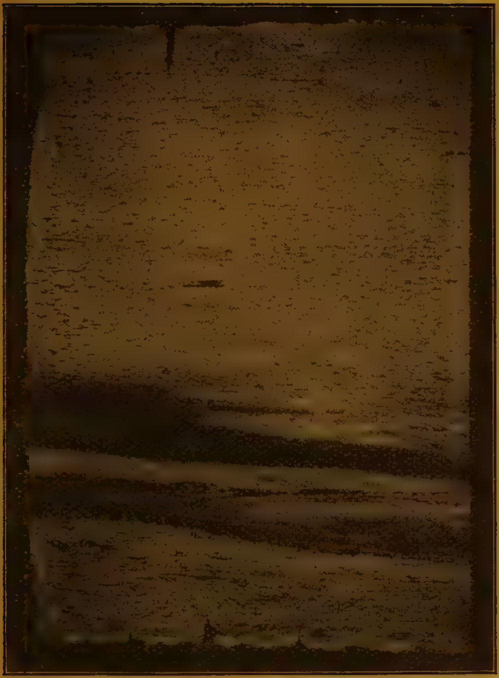


Fig. 33. — Corrosion fatigue fracture of an axle (showing fracture at left and further fissures at right).

A few other cases of welded axles sent to us for examination were wheel seat fractures from a sleeping car, an express train coach, a vehicle of unspecified type, and three tenders. Welding had been applied to build up worn surfaces, as in figure 34. The mecanical properties and chemical composition were similar to those of the axle just described, and the structure showed no special defect. It may be that these fractures should be classed as simple wheel seat fractures, and that the welding-on did not exert a supplemantary detrimental effect.

In conclusion, reference may be made to a class of axle breakages which attracted much attention before the war.

Crank axle breakages.

We have rarely had fractures of this type to examine during the past decade. All the axles concerned (six in number) were delivered during the period 1918-1921 and, owing to the scarcity of raw materials still prevailing at that time, the percentage of alloying elements was low. The alloys used contained either manganese up to 1.7 % without nickel or chromium, or nickel alone up to 1.6 %, whereas our specifications now call for (5 ± 0.5) % nickel. Two of the axles were fissured or contained impurities respectively; in three axles the endurance strength was not higher than that of an ordinary St. 50 steel (see Table 7). There were no other defects of material with the exception of one of the breakages which was also a wheel seat fracture. As shown by figure 35 there is here one of the few internal fatigue fractures which also occur occasionally in crank pins. They are attributable to forging cracks, to which the material concerned is liable. Examination of a longitudinal section showed that the forging crack was repeated at a certain

Fig. 34. — Metal added to axle by welding.

TABLE 7. — Test res

Serial number.	Report No.	Vehicle.	Elongation °/°	Tensile strength, kgr./mm² (*Engl. tons/in²*).	Yield point, kgr./mm² (*Engl. tons in/²*).	Endurance stre (alternating ben kgr./mm² (*Engl. tons/i*
1	2	3	4	5	6	7
1	5 663	58 1870	...	... ...	... ...	... ...
2	7 799	17 133	26–27	52 (*33.0*)	32—33 (*20.3—20.9*)	... ...
3	8 561	58 1813	26—27	57 (*36.2*)	33.6 (*21.3*)	22 (*14.*
4	8 692	58 1027	17—21	61—62 (*38.7–39.3*)	26 (*16 5*)	22 (*14.*
5	11 795	S 10	28—30	57—58 (*36.2—36.8*)	32—34 (*20.3—21.6*)	23 (*14.*
6	12 420	58 1754	....	69 (*43.8*)	... ...	... ...

(*) Surface fissure. — (**) Nickel 1.6 °/₀. — (†) Forging crack.

distance from the fracture. Although the crack extended over about 9/10 of the section, this axle, which broke in 1931, bore the date 1919. It was thus about 10 years in service and this case illustrates, from the opposite standpoint, the fact which runs through all our knowledge and observation of wheel seat fractures :

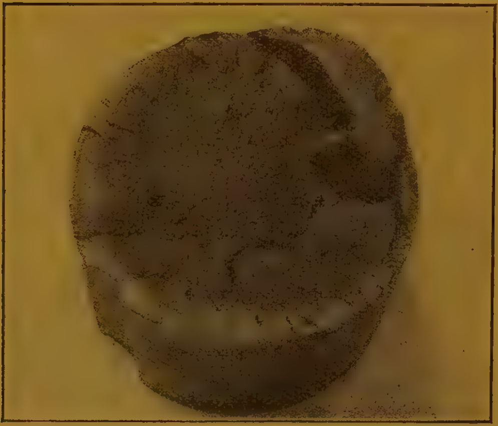


Fig. 35. — Internal fatigue fracture in crank axle, due to forging cracks.

If the surface of the axle is smooth and not affected adversely by supplementary factors, there may be relatively large internal defects, yet the axle may remain in service for a long time, if not indefinitely, without breakage. On the other hand, the axle may be thoroughly sound and yet lose at once a large part of its endurance strength owing to the notch-effect of a wheel boss or collar.

Unfortunately, from the nature of bending stress, the whole section of the part concerned cannot share uniformly in the load, but the outer fibres, which are most exposed to injury, are subjected to the highest stress. Any damage to the surface, and any collar effect are therefore much more dangerous than is commonly supposed and than calculations show, because they must be taken in relation to the surface layer, 0.1 mm. (0.0039 inch) or so in thickness, which has to carry the maximum load, and not the whole section. With a rapid alternation of load, the inner zones of the cross-section cannot participate in the load to the desirable extent. As in the analogous case of high voltage discharge, the stress under repeated alternation of load affects only the peripheral zones, roken crank axles.

Impact value Kg.-M./cm^2 (*ft.-lb./in*^{2}). 8	Impact endurance of notched bar. 9	Proportion of fatigue fracture. 10	C 11	Si 12	Mn 13	P 14	S 15	Year of delivery. 16	Year of fracture. 17	Remarks. 18
...	...	...	...	...	...	..	..	1921	1926	Much cracked.
10.3 (*345.3—480.6*)	..	...	...	...	...	..	...	1920	1928	
9.9 (*410.6—461.9*)	9 100	4/5	0.28	0.34	1.73	0.01	0.03	1920	1929	
7.7 (*252.0—359.3*)	10 000	3/4	0.36	0.28	1.31	0.02	0.04	1918	1929	Segregation and blowholes.
9.1 (*368.6—424.6*)	8 200	(*)	0.20	0.29	0.41(*)	0.01	0.02	1920	1931	
...	...	(†)	0.41	0 23	1.55	0.03	0.05	1919	1931	

the remainder of the section being unable to take its share.

Summary :

Reviewing the results of all investigations and observations on axle breakages, it may be said that, as regards locomotives, passenger coaches and goods wagons, the number of breakages observed is very low. In so far as they are due to running hot, their timely elimination is made possible by the open initial fissure which will be discovered during the course of repairs. The distinctive nature of the fracture, fully illustrated by examples, will facilitate the recognition of the cause of such journal fractures in future and, in most cases, will make an examination of the material unnecessary. Keyway and wheel seat fractures are mostly caused by exceptional supplementary stresses which, it would appear, seldom arise. Even the dangerous collar effect of the wheel boss, demonstrated on the testing machine, appears to be reasonably covered by the margin of safety allowed in design. In order that the provision made by the designer, to cover unforseen and indeterminate stresses, may not be sacrificed during construction, it is important that more attention be paid to the fatigue testing of assembled components. Numerical data can thus be supplied to the designers concerning the weakness or danger of any particular form of construction.

In the case of axles such data is now available and, for roller bearings in particular, constructional measures have long been introduced for the prevention of axle breakage. It is to be hoped that the already small number of axle breakages of all kinds will be further reduced. If, contrary to expectation however, axle breakages should occur to an increased extent under any vehicle the information now presented should provides a basis on which to make systematic observations and the preliminary work towards remedying the trouble and reducing it. Also, these notes should be of assistance to those who are dealing with new questions arising in the manufacture of wheel sets, by indicating where danger lies and how it may be avoided.

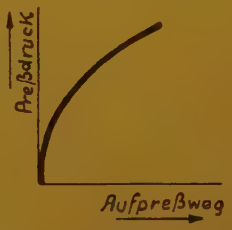
Discussion.

Herr Oberingenieur WIDDECKE : It is gratifying to find our reflections concerning the cause and prevention of axle breakages confirmed by the exhaustive investigations of Dr. Kühnel. The author's interesting examples agree remarkably with my own experience acquired during the past quarter of a century concerning recurrent and isolated cases of axles breakages on several foreign railways.

Every axle breakage under a running train represents a danger. Fortunately the result of the breakage is generally less serious than might be expected. In a certain new type of locomotives breakage of driving axles occurred, during slow running on severe gradients, starting from the keyway which was extended with a marked taper to the end of the wheel seat where, moreover, a mistake in boring the boss too large had been corrected by giving the axle a larger diameter at the wheel seat, with a small radius between it and the journal. At the small radius connection there was a sudden divergence of the lines of stress, already interrupted and distorted by the keyway; so that, together with the serious compression of the axle by the rigid boss, everything conspired to produce such a concentration of stresses at the end of the keyway that the fatigue fracture started from this point. An easy transition from the wheel seat to the journal, a setting back of the keyway, and careful pressing on of the wheels, after changing all the driving axles in this series, prevented any further breakages, notwithstanding the heavy mountain service. These breakages were a costly lesson to the builders.

Another case of breakage due to notch effect occurred in a tender axle of an express train while running at full speed. This was one of the rare cases in which an axle broke in the middle and not at the wheel seat. Investigation showed that a groove must have been worn in the axle by the rubbing of a brake rod, and this groove had been filled up by welding. The repair shop man concerned was evidently unaware of the very serious influence of such grooving as a cause of fatigue fracture. The axle ought unquestionably to have been changed, and in any case ought never to have been welded up. In general, axles should never be welded or built-up by welding where bending or torsional stress can arise.

A remarkable epidemic of breakages in wagon axles of English, German and American origin led to a careful investigation by a foreign railway company about 10 years ago. The causes, individual and in combination, were found to be similar to those mentioned by Dr. Kühnel. Excellent statistical data concerning the history of the axles facilitated the investigation. Conditions were aggravated in the case of this overseas railway by the fact that the axles were often severely stressed by running over so-called *transition pieces,* where the wheels — as with Vögele curves and many tramway crossings — are carried by the flanges whereby, apart from the inertia effect of running up at high speed, there results a sudden increase in bending moment in the usual zone of these fractures, 0.25 mm. (0.0098 inch) from the inside of the wheel seat. Some of the fractures were due to and originated in fine grooves formed when turning the axles at the wheel seats. Pressing wheels onto the axles with excessive pressure has a similar effect, particularly if the axle wheel seat is truly cylindrical and the bore of the boss



Note : Pressdruck = Force exerted by press. — Aufpressweg = Distance wheel is forced on to axle.

tapers somewhat towards the inside. When such a wheel is pressed on, the relation between force and distance is as shown by the accompanying diagram hereafter. The boss then grips the axle abnormally at the inner end of its seating, and the course of the lines of stress is heavily distorted at this point when the axle is running under load and somewhat deflected as far as the part within the boss. A slight enlargement of the boss for about 20 mm. (3/4 inch) permits of a smoother progression of stress in this highly stressed part of the axle. The same applies to the rings pressed on to the journals for roller bearings, with which according to Dr. Kühnel a number of fatigue fractures have occurred during recent years, owing to the notch-effect of the sharpedges of these shrunk-on rings. The loss of camber of the springs of overloaded goods wagons also results in the imposition of very severe additional loads on the axles when running over rail joints or badly laid crossings, and this may initiate fatigue fractures. I saw recently on a railway in Asia, where it is not uncommon for wagon bodies to be loaded so as to rest on the axle boxes, another instance of axle breakage close behind the inner end of the wheel seat, resulting in a serious accident with heavy material damage.

The more widely discrimination concerning the causes of such axle breakages is disseminated in drawing offices, in workshops and in the operating service, the more rarely will these breakages occur with all their dangers, interruptions of service, and cost.

Herr Direktor KREISSIG : The author's remarks are of special importance to us designers, since they show, in a striking manner, that design must be based on technical requirements. Constructional conditions and technological data are often at variance and the designer has to devise a solution acceptable from both points of view. In this connection, the author's remarks concerning wheel seat fractures are specially valuable, and I have certainly learnt a great deal today.

One is astounded by the results of the tests on an axle with a shrunk-on boss and a similar piece machined from the solid : the fatigue strength at the fracture was the same in both cases, showing that the concentration or heaping-up of material was the cause of breakage. The agreement between the dynamic strengths is so startling that I should like to ask the author whether the tests were repeated often enough to obtain a good average.

Not so very long ago I had an opportunity of studying a series of axle breakages which occurred very frequently in a certain delivery. The axles broke in the boss not, as usual, 6 to 8 mm. (1/4 to 5/16 inch) from the entrance but about 25 to 30 mm. (1 to 1 3/16 inches) inside the boss. A rim or rust 25-30 mm. (1 to 1 3/16 inches) in breadth formed inside the boss and the fracture occurred at the end of the rust zone. The axles appear to have been true to size, and form, so that the occurrence noted is not easily explicable. I should be grateful if the author would say whether he has come across similar fractures and, if so, what is their cause.

Herr Dr.-Ing. LEHR : I can fully confirm, from the results of my own investigations, the author's statement that wheel bosses are as detrimental as a small radius to the endurance strength of a shaft. This is true not only as regards bending stresses, but also as regards alternating torsion. In the latter case, it is remarkable that the fractures at sudden changes of section or the wheel seats are generally perpendicular to the axis, whereas the fracture is generally helical in the case of a smooth shaft of uniform area. Also, there is a very considerable reduction in strength.

I also wish to refer to the disastrous consequences formerly observed in large gas engines owing to the nocht-effect of bosses. The breakages occurred in crankshafts of the largest dimensions, the crank webbs being shrunk on to the shaft. Here again the endurance strength was reduced by about 50 %. These difficulties have disappeared since the ends of the bores of the bosses have been slightly enlarged in a progressive way so as to secure smooth transition, eliminating edge effect and chafing. The deflection of the shaft is then no longer accompanied by irregularity of stress distribution at the boss. In this connection, it may be noted that breakages due to oscillation of overhead power lines nearly always occur at the clamps; here again, there is a short of boss action which reduces the endurance strength of the conductor to a fraction of its normal value. These difficulties have been practically eliminated by appropriate design of the clamps.

The author has referred to the unfavourable effect on endurance strength of welding-on metal. In this connection it may be interesting to refer to certain tests which I carried out in the laboratory of Messrs. Schenck, Darmstadt. The endurance strength of flat bars with X — welds was investigated by means of the bending apparatus of a Schenck torsional fatigue machine. The loading was constant over the whole test length, and was measured accurately by means of a dynamometer and not calculated from the deflection. The following table gives an abstract of the results. The endurance strength $\sigma\frac{S}{W}$ of the welded speci-

Data from endurance tests on welded flat bars, at n = 3 000/min.

Base material : C 0.20 %; Si 0.18 %; Mn 0.7 %		$\sigma_B = 43$ kgr./mm^2 (*27.3 Engl. tons/in*^{2}) $\sigma_S = 28$ $\delta = 22$ %
Endurance strength under alternating bending : $\sigma^0_W = 22$ kgr./mm^2 (*14.0 Engl. tons in/*^{2})		
Arkos-Aachen Reformend	$\sigma_B = 38$ kgr./mm^2 (*24.1 Engl tons/in*^{2}) $\delta = 10$ %	$\sigma^s_W = 15.5$ kgr./mm^2 (*9.8 Engl. tons/in*^{2}) $\Delta_s = \frac{\sigma^s_W}{\sigma^0_W} = 0.705$
Arkos-Aachen Tensilend	$\sigma_B = 45—55$ kgr./mm^2 (*28.6 to 34.9 Engl. tons/in*^{2}) $\delta = 24—26$ %	$\sigma^s_W = 17$ kgr./mm^2 (*10.8 Engl tons/in*^{2}) $\Delta_s = \frac{\sigma^s_W}{\sigma_{W}} = 0.773$
Böhler B. W.	$\sigma_B = \sim 50$ kgr./mm^2 (*31.7 Engl. tons/in*^{2})	$\sigma^s_W = 16.5$ kgr./mm^2 (*10.5 Engl. tons/in*^{2}) $\Delta_s = 0.75$
Böhler Elite	$\sigma_B = \sim 50$ kgr./mm^2 (*31.7 Engl. tons/in*^{2})	$\sigma^s_W = 17.5$ kgr./mm^2 (*11.1 Engl. tons/in*^{2}) $\Delta_s = 0.796$
Bochumer Verein Blankdraht	Weld annealed	$\sigma^s_W = 11.0$ kgr./mm^2 (*7.0 Engl. tons/in*^{2}) $\Delta_s = 0.50$
	Weld unannealed	$\sigma^s_W = 13.5$ kgr./mm^2 (*8.57 Engl. tons/in*^{2}) $\Delta_s = 0.614$

men is compared with that of a solid specimen of the same material. In the most favourable case the endurance strength of the welded specimen is 77 %, and 50 % in the most unfavourable case of a carefully made weld. In the case of careless workmanship, the fatigue strength may even decrease much more. The fractures of the welded specimens always commence at the boundary between the penetration of the weld and the base metal. No case has been observed in which the fracture was solely through the weld material. The edge of the penetration zone is the danger point. Now, the same danger occurs where building-up (of worn parts, etc.) is effected by welding, and one must certainly reckon that the endurance strength will be reduced by 30 to 50 %. Further tests are however desirable to confirm this conclusion, and the investigation of this question deserves the closest attention.

In conclusion, I may refer to the endurance strength of bolts, which I also investigated in the laboratory of Messrs. Schenck, Darmstadt. The tests were made on a static-dynamic tension-compression machine giving 1 000 alternations of load per minute. Numerous tests were made on bolts with 1/2-inch, 5/8-inch and 3/4 inch threads, and in all cases an initial static load of 12 kgr./mm² (7.6 Engl. tons per sq inch) was imposed, referred to the core section. The bolts were found to have an endurance strength (superimposed on the stated initial stress of ± 4 to 4.5 kgr./mm² (± 2.54 to 2.86 Engl. tons per sq. in.) using ordinary bolt steel, and of ± 5 to 5.5 kgr./mm² (± 3.2 to 3.5 Engl. ton per sq. in.), using steel 50.11. The basic endurance strength of the material itself was ± 13 to 14 kgr./mm² (± 8.2 to 8.9 Engl. tons per sq. in.) in the first case; and ± 16 kgr./mm² (± 10.1 Engl. tons per sq. in.) in the second case, again with an initial stress of 12 kgr./mm² (7.6 Engl. tons per sq. in.) in both instances. All stresses are referred to the core section of the bolts. The accumulation of stresses in the threads thus results in the reduction of the endurance strength to about one-third. Breakage generally occurs where the thread leaves the nut. A considerable increase in endurance strength can be obtained by extending the nut beyond the thread on the bolt, and by reducing the diameter of the bolt behind the thread to 8/10 of the core diameter, the transition being well rounded. In the case in question, the endurance strength of screws of steel 50.11 is increased from 5.5 to 8 kgr./mm² (3.5 to 5.1 Engl. tons per sq. in.). Maybach has acquired similar experience from practical operation. Here again it was found that a considerable increase in endurance strength resulted if the thread of the bolt did not project beyond the nut. I attribute this peculiar phenomenon to the fact that a gradual equalisation of stresses occurs in the latter case, reducing the local concentration of stress which occurs in any ordinary screw. It might be investigated whether a further increase in endurance strength could be obtained by reducing the bearing surface of the first turns of the thread in the nut by boring the latter somewhat taper so that the upper turns contribute more than hitherto to the transmission of the forces.

Herr Dr. HAMMER : It is particularly satisfactory that axle breakages now give rise to little anxiety. This was not the case in the days of my apprenticeship. For example, we were greatly troubled by innumerable breakages of tender axles, particularly during a severe winter, and the reduction of the water and coal capacities of the six-wheeled tender was under consideration. Then there was the case of eight-coupled goods locomotives, in which nearly 100 axle breakages occurred. Exhaustive measures were taken to guard against such mishaps. First, however, about 1 500 new wheel sets had to be provided for the 15-m^3 (530 cubic feet) tenders. Also, larger axles were fitted to the tenders. At that time, too, I believe, the provision was made that recording pressure gauges should be used when pressing-on wheels to ensure that the pressure rose steadily. Conical wheel bores were prohibited. Values were laid down for the final pressure according to the diameter of the axle (now still between 400 and 700 kgr. for locomotive and tender wheel sets, and between 400 and 600 kgr. for wagons wheel sets par mm. diameter of the wheel seating [22 400 and 39 200 lb. — and 22 400 and 33 600 lb. per inch diameter respectively]. Also, it was prescribed that the edges of the bore of the boss should be rounded in order to avoid notch-effect and the consequences of a sudden change of section.

As regards coupled axles, it was laid down that the keyway must not be carried through to the inside of the boss, and must not be cut with square cornered milling cutters, but must be rounded and must taper off gradually towards the inside of the boss. It seems that these old experiences have been neglected in pressing the inner ring of roller bearings on to the axle journals. Dr. Kühnel has therefore rendered valuable service by his scientific investigations which prove clearly how injurious a sudden change of section on the axle may be.

Dr. KÜHNEL : The remarks of the various speakers constitute, in the main, a valuable confirmation of our observations so that the reply can be quite short. In reply to Herr Direktor Kreissig, I may say that we have encountered more breakages inside the wheel seat in the course of our experiments on the testing machine. In this case, however, the wheel seat did not bear properly up to the incipient fracture. I did not wish to go into details in my paper, otherwise I could have mentioned this fact. I can confirm that we checked the results concerning notch-effect of wheel seats by control tests, hence we do not regard the values obtained as chance results.

[621 .335 (.82) & 621 .43 (.82)]

Oil-electric units for the Buenos Ayres Great Southern Railway.

(From *Engineering*, 2 December 1932 and 24 March 1933 issues.)

Speaking at a luncheon held in connection with a demonstration of new Diesel-electric locomotive stock at the works of Messrs. Sir W. G. Armstrong Whitworth and Company (Engineers), Limited, Newcastle, Sir Brodie Henderson gave some interesting information on the performance of the two 1 200-H. P. locomotives of this type in use on the Buenos Ayres Great Southern Railway. He said that these units were working on the home section of the railway, where the terminal stations handle some 130 000 passengers daily, approximately the same as the number using Waterloo Station on the Southern Railway. The locomotives were employed on local services, and usually operated in conjunction with, and to the same time-table as, the company's ordinary steam locomotives. The oil units were thus somewhat hampered, but after numerous trial runs, it was found that they were capable of giving a service equivalent in every way to that obtained from ordinary electrical stock on neighbouring railways. The trains operated by the Diesel-electric locomotives had a capacity of 600 passengers, and the fuel oil consumption worked out at 9.4 lb. per train-mile. The two units had now run some 160 000 miles, and on one which was recently opened up, there were practically no signs of wear. As a result of the experience gained with the 1 200-H. P. locomotives, an order had been placed with Messrs. Armstrong Whitworth for three units of 1 700 H. P. each. Both the older and two of the new units are in reality mobile power houses, since they supply current not only to the motors on their own axles, but also to motors on the axles of the carriages, the latter being designed to run on electrified lines on certain parts of the system.

The new power houses, one of which is illustrated in figures 1 to 4 are designed to propel trains consisting of at least eight coaches, each having a length of 83 ft. 6 in., and giving a total train passenger capacity of about 1 000. The gross train weight will be about 550 tons, and the maximum designed speed is 70 m.p.h. As will be clear from the figures, the mobile power houses are each made up of two articulated units. Each of these units is fitted with an 850-brake horse-power eight-cylinder Armstrong-Sulzer engine direct coupled to its generator. Each articulated unit is mounted on two bogies, and is equipped with two geared traction motors for its own propulsion. Each 850-brake horse-power set supplies current to half the train motors, so that even in the unlikely event of failure of one of the units, the train could proceed at reduced speed with the power supplied by the remaining set. The maximum acceleration of the train is automatically controlled to prevent overloading of the engines, and the usual dead man's handle is fitted. The engine is also automatically brought to rest in the event of a failure in the lubricating oil or cooling water supplies. One of the articulated units is being equipped for locomotive work, two sets of motor reduction gearing being provided to give alternative tractive efforts for freight or passenger working. When geared for freight working, the maximum tractive effort is 66 000 lb. and the maximum speed 40 m.p.h., while when geared for passenger working, the maximum tractive effort is 39 000 lb., and the maximum speed 70 m.p.h. The unit in this case is equipped with six traction motors, two on each of the inner bogies, and one on each outer bogie. A driver's compartment is provided at each end of the locomotive with duplicated controls, and the whole of the power-generating equipment is interchangeable with that of the mobile power houses. The maximum axle load is 18 1/4 tons, and the total weight of the locomotive in working order is 145 tons. The gauge is 5 ft. 6 in., the overall width is 10 ft. 6 in., and the overall length is 71 ft. 6 in. The fuel tanks have a capacity of 5 tons, sufficient for approximately 24 working hours.

In addition to the units described, a multiple-unit motor coach and two Diesel-electric shunting locomotives were on view in Messrs. Armstrong Whitworth's works at the demonstration already referred to. One of the motor coaches was described in *Engineering*, vol. CXXXIII, 1932, p. 10, but it may be mentioned that a unit of this type, the « Tyneside Venturer », has recently completed six months' service in the Tyneside district. In this period, it has run 25 054 miles without any loss of time or traffic delays, at a running cost for fuel of 0.59 pence per mile; for lubricating oil, including cleaning, of 0.11 pence per mile; and for maintenance, including fuelling and oiling daily, but excluding coach cleaning, of 0.28 pence per mile, giving a total running cost of 0.98 pence per mile. It is stated that when the cost of superintendence, wages, and so on, is added, and assuming a reasonable maintenance cost to cover the life of the vehicle, the locomotive cost per train-mile for a two-coach set, with 140 to 150 seats, works out at 5 1/2 pence or 6 pence for a three-coach set with 220 to 240 seats.

The larger of the two shunting locomotives to which reference has been made is illustrated in figure 7. This is a 40-ton, six-coupled unit with a tractive effort of 24 000 lb. It is equipped with a standard Armstrong - Sulzer engine coupled to a generator, the latter supplying power to a single traction motor. This motor is coupled to all six wheels by a jack shaft and connecting rods. The engine is a six-cylinder unit developing 250 brake horse-power, and is generally similar to that fitted to the rail car, previously described. The engine is stopped and started electrically, and is only running when power is required. The controls are duplicated on either side of the cab so that the driver can work easily at the best position in any given circumstances. The locomotive illustrated has been in regular service in goods and mineral yards on the London and North Eastern Railway for the past four months, and has given entire satisfaction. It has worked some 2 265 hours in this period, with a service availability of 98.8 per cent. and has hauled loads up to 816 tons, on a 1 in 150 grade. The running costs per locomotive-hour have averaged 7.8 d. for fuel and 1.96 d. for lubricating oil, including cleaning, and 3.25 d. for maintenance. The smaller locomotive shown on the occasion of the demonstration was a 15-ton, four-coupled unit, fitted with a power plant similar to that on the locomotive rail-car described in *Engineering*, vol. CXXXIV, 1932, p. 488.

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Through the courtesy of the builders, we are now able to give further particulars of the two 1 700-H. P. mobile power-houses, and a locomotive of simi-

Fig. 1.

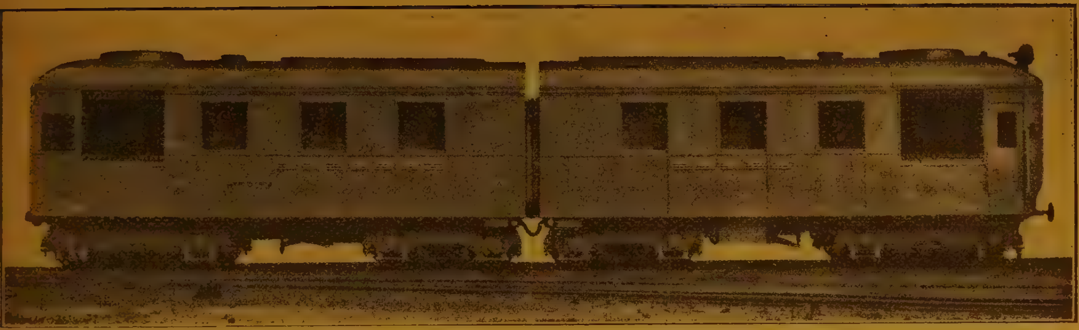
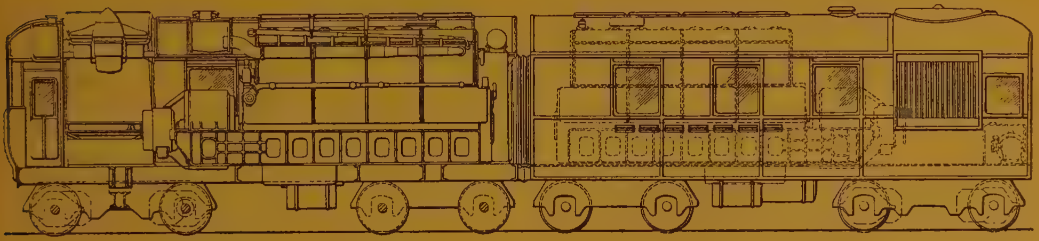


Fig. 2.



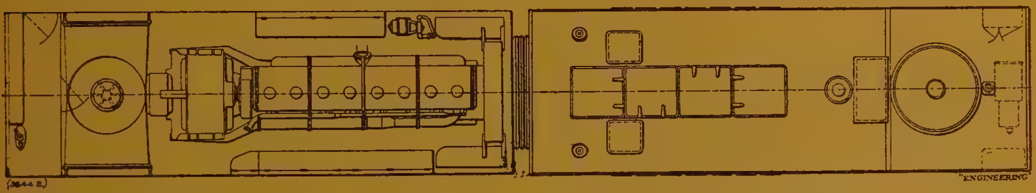


Fig. 3.

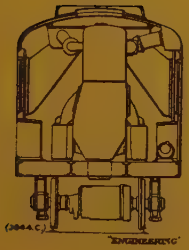
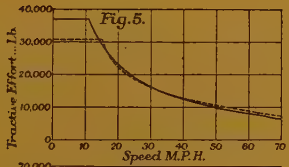
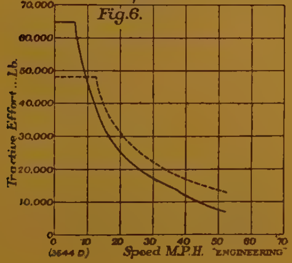


Fig. 4.





Figs. 5 and 6.

lar power, for use on the Buenos Ayres Great Southern Railway, but before describing them in detail, we give a resumé of the particular duties for which they were designed. As stated above, the mobile power-houses are to form part of suburban eight-coach electric trains, while the locomotive is intended both for main line express passenger and heavy goods work, a second set of driving wheels and axles being supplied to enable it to fulfil this dual function. Two suburban train sets, with 1 200-H. P. mobile power-houses, have been in use on the line since 1929, all the coaches being fitted with motors which obtained their supply from the power houses, instead of on the third-rail system from an outside source. The power-houses themselves are also fitted with motors. Except for the elimination of the usual train-starting resistances, rendered possible by the drivers' ability to control the electric supply at its source, the trains operate in the same manner as ordinary electric trains, taking advantage of the weight of the passenger coaches to give the adhesion necessary for quick acceleration. They can run in either direction, and during rush hours, two five-coach trains can be coupled together in multiple unit and run as a ten-coach train, only one motorman being required in addition to the guard. Experience showed that under the particular operating conditions on the railway, the multiple-unit feature was not required, and that an eight-coach train, with a seating capacity of 1 000, would be most satisfactory.

Orders covering three such trains were placed with Messrs. Armstrong Whitworth, for the mobile power houses; and with Messrs. The English Electric Company, Limited, of London and Preston, for the electric traction motors of the trains, the passenger coaches being built by the company themselves. Messrs. Armstrong Whitworth, who had built the two previous 1 200 brake horsepower mobile power houses for the installation of Sulzer Diesel power sets ordered from Switzerland by the railway, were, on this occasion, entrusted with the complete contract. A contract was also placed with the same firm for the main-line Diesel locomotive. For the purpose of standardisation, as well as for technical reasons, electric transmission for this unit was also chosen, since electric generators driven by Diesel-engines having been selected for the electric suburban trains, identical engine-generator sets could then be used in the locomotive.

The 1 700 brake horse-power plant being divided into two 850 engine-generator sets, as stated, two double-bogie vehicles, close-coupled and connected by bellows, were decided upon. The power house being permanently attached to one end of the train, one driver's cab only is required on this unit, a second driver's cab being provided at the other end of the train in the end passenger coach. The coupling between the power house and coaches, and between the coaches themselves, is in accordance with the Saccaggio patent, in which tie bars between the bogie centres form the coupling between two coaches. By this scheme, the construction of the coach underframes is considerably lightened, and the permissible length of body is increased to 80 feet. In addition, power being applied uniformly throughout the train by the two axle-suspended motors on each coach, very light buffing stresses are involved, and further lightening of the passenger stock is made possible. Four motors are fitted on the power house, and 16 on the rest of the train, there being one per passenger-coach bogie.

The power houses have an overall length of 65 feet, and the distance between the bogie centres in each vehicle is 20 feet. The loading gauge allows an ample gangway on each side of the engines, while the maximum axle loading of 16 1/2 tons is somewhat less than that of the steam locomotives at present in use. The bogies, shown in figures 2 and 4, are of plate frame construction, similar to the Company's standard carriage bogie, each main side frame consisting of two plates spaced by channel sections, giving great rigidity and strength with minimum weight. The double plates enclose the laminated axlebox springs, thus permitting central loading of the axleboxes and obviating twisting of the frame by overhung suspension brackets. The outer bogies, on which the four motors are mounted, have a wheelbase of 8 ft.4 in., as compared with 6 ft. 6 in. for the inner bogies, the arrangement giving better riding properties at high speed. The outer bogie of each half unit has a swing-link bolster fitted with laminated and helical springs. The inner bogies have fixed bolsters without springs. The auxiliary bearing springs are of rubber on the motor bogies, and of the helical type on the carrying bogies. Roller bearing axleboxes, made by Messrs. J. Stone and Company, Limited, of Deptford, are employed on the power house and throughout the train. Braking is effected by blocks on all wheels, the hangers being placed towards the middle of the bogie inside the wheelbase. No sand boxes are fitted, as the ratio of adhesive weight to total weight of the train is ample even for the severe acceleration of a suburban service. The underframes are composed of four main longitudinal members, the inner ones, on which the engine-generator sets are carried, being heavy rolled-steel H beams, whilst the outer members are of steel channel section. All are well braced by cross stays, and at the driving compartment end, the frames are fitted with side buffers and a screw-coupling hook. The connection between the two halves of the power house is made by a central adjustable tie rod, pivoted near the bogie centres, and passing through buffing blocks on the inner ends of the frames.

The two 850-B.H.P. Diesel engines, each forming one unit with the generator for lifting purposes, and also for maintaining rigid alignment independent of the vehicle underframe, were supplied to Messrs. Armstrong Whitworth by Messrs. Sulzer Brothers, of Winterthur, complete with Brown-Boveri generators, auxiliary generators, and starting batteries. Arrangements have now been made so that all future engines will be entirely British built at Messrs. Armstrong Whitworth's Newcastle Works. Each engine is an eight-cylinder, airless-injection, four-stroke unit, of the type manufactured by Messrs. Sulzer and Armstrong-Whitworth, especially for railway-traction purposes, and rated continuously at 850 B. H. P. at 550 r.p.m., with one reduced speed for idling only. The construction of the engine is generally similar to that of the somewhat smaller eight-cylinder model described in *Engineering,* vol. CXXXII, page 210 (1931).

Each of the two 570-kw. direct-current generators is connected to a pair of power cables running the length of the train, and alternate bogies of the train are feld by one or other of these power cables. The two electric supplies and the two sets of traction motors are, therefore, completely independent, and the train can be run, if necessary, on one supply only. The current is carried between the coaches by flexible cables supported in cable connection boxes, and since the train is permanently made up in an eight-coach set, no removable couplers for the heavy supply cables are required, though for purposes of easy disconnection, the multi-wire control cables throughout the train are fitted with English Electric multi-way coupler plugs and sockets of the usual motor-coach type. The starting tractive effort of the train is over 60 000 lb., giving an initial acceleration of about 1 m.p.h. per second; the maximum speed is 70 m.p.h. The traction motors are of the usual axle-suspended, self-ventilated, series type, wound for 750 volts, and drive through simple spur reduction gearing in oil-tight gear cases. Series-parallel control of the motors is not required, since the driver has control of the source of supply, and the motors are fed at a low voltage during starting. It is claimed that the arrangement adopted, and the absence of voltage surges, owing to the independent power of each train, considerably reduces the maintenance of the equipment as compared with trains drawing their supply from a third rail or overhead wire.

The auxiliary equipment of the power sets includes an engine-starting battery of nickel-iron cells and two auxiliary generators driven by the main engine, and mounted on an extension of the main generator shaft. These small generators supply current at 120 volts for the purpose of charging the battery, and also supply current to the radiator-fan motors, exhaust, etc. The water and oil-cooling apparatus consists of Serck radiator elements in aluminium headers mounted on both sides of the vehicles, as shown in figures 1 and 2. Aluminium ducts lead to central openings in the roof, the fan motor, shown in figure 2, assisted by the natural circulation of the warm air, drawing air through the radiators and expelling it through the roof.

Multi-core cables running the length of the train connect the driver's controller at each end of the train to the motor-reversers and line contactors mounted on the underframes of the passenger coaches, and also to the power sets for the purpose of starting and stopping the engines, etc. Driving is effected in the same manner as in normal electric trains. The control apparatus was supplied by Messrs. The English Electric Company to the Chief Mechanical Engineer's specification.

The superstructures consist of a welded framework of rolled-steel sections, on which aluminium sheeting is fixed by rivets. At the vestibules, where additional strength is required, the sheets are of steel. The end lights are fixed, and all lights in the driving compartment have Triplex glass. The side lights are fitted in Alpax sliding frames with white opalescent armoured glass. Hinged ventilators are fitted in the roof above the engines, and the driving compartment is fitted with torpedo ventilators. The air ducts from the oil and water coolers are built into the sides of the bodies and lead into a central fan fairing fitted in the roof. Insulation of the panels against heat-transference and noise has been improved by spraying the panels, previous to painting, with flaked asbestos impregnated with a binding composition. The fuel, water, oil, air and electrical piping circuits are distinctively coloured for ease in tracing.

Vacuum braking is used in accordance with the Railway Company's standard. A Reavell exhauster, motor driven off the auxiliary supply, is installed in each power house at the end remote from the driver, and acts as a vacuum pump for the single-pipe train braking system. One brake cylinder for each bogie operates four brake blocks, one for each wheel, through the usual brake rigging. Driver's brake valves, vacuum horns and emergency valves are installed in the two driving positions at the ends of the train, the emergency valves being controlled by the dead man's button on the driver's controllers in such a manner that, in the event of accident to the driver, the trains brakes are automatically applied, in addition to power being cut off from the train. The brake apparatus was supplied by Messrs. Consolidated Brake and Engineering Company, Limited, of Slough.

As mentioned above, the locomotive is fitted with identical generator sets and auxiliary equipment to the power houses, and does not therefore require

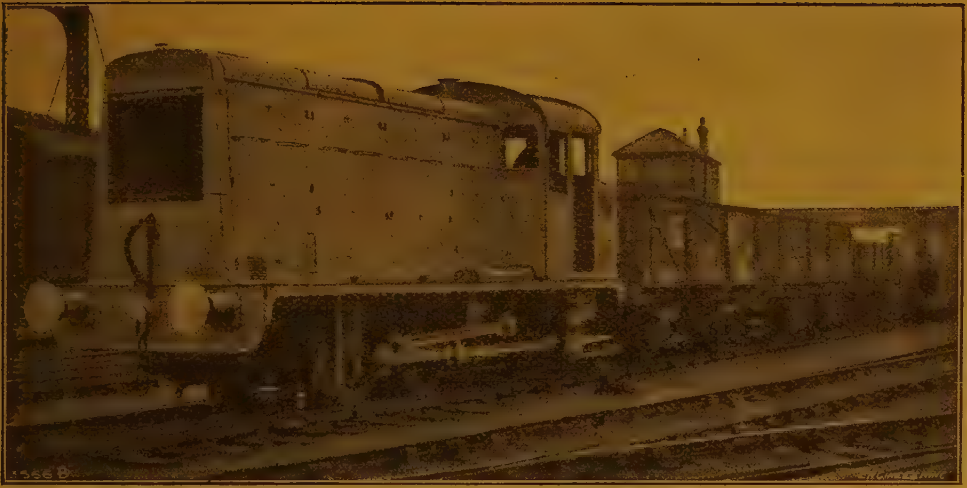


Fig. 7. — Shunting locomotive.

detailed description. Future requirements will be met by purchasing a certain number of locomotives with passenger gear ratios for the electric traction motors, and others with freight gear ratios, while a stock of spare wheels and axles will enable sufficient of each type to be available as demand arises. Thus, during the harvest season, when grain shipments are heavy, some of the passenger locomotives can be converted to freight use, this provision enabling the total number of locomotives required to be reduced to a minimum. As already stated, a spare set of wheels and axles has been supplied with the first locomotive, so that it can be tried out thoroughly in both classes of service. The tractive effort at various speeds is shown by the full curve in figure 5 with the passenger-gear ratio, and by the same curve in figure 6 with the freight-gear ratio. The dotted lines on the two figures show the corresponding curves for typical steam locomotives, that in figure 5 being for a 175-ton 4-6-2 type engine, and that in figure 6 for a 198-ton engine of the 2-8-2 type. All the work on both the mobile power houses and the locomotive has been carried out to designs prepared by the Consulting Engineers, Messrs. Livesey and Henderson, and the Chief Mechanical Engineer of the Railway, Mr. P. C. Saccaggio.

[621. 132.8 (.42)]

Recently built « Sentinel-Cammell » steam railcars.

(*The Railway Gazette.*)

By the courtesy of the « Sentinel » Waggon Works Limited we have been enabled to reproduce herewith illustrations and particulars of two new types of « Sentinel-Cammell » railcars built respectively for the London & North Eastern Railway and the Roumanian State Railways.

The first of the London & North Eastern Railway cars was delivered in October 1932 and the cars for Roumania were shipped in January 1933. The London & North Eastern Railway vehicles have been designed specially for working at good speeds over very heavy gradients and to give a high standard of comfort to passengers. The construction of the coach follows the usual standard lines, the body being carried on two bogies, one axle of each bogie being driven by a separate engine slung beneath the main frame. A three-drum water-tube boiler of the Woolnough type, supplying ample steam for both engines and accessories, is placed at one end of the coach, with a driver's compartment in front of it, while at the other end is another driver's compartment in which all controls are duplicated so that the car can be driven with equal facility in either direction.

The engines and boiler are generally as in previous cars of similar type already described, but improvements have been incorporated in both which have resulted in a substantial increase in power. The feed pump, which was formerly driven from the engine, has been replaced by a steam-driven pump taking its power direct from the boiler. Modifications have also been made in the valve gear, the steaming capacity of the boiler has been increased and a specially designed feed water heater incorporated, so that fully 300 H. P. is now continuously available on the intermediate cut-off.

The interior is furnished with seats of the semi-bucket type for the accommodation of 48 passengers. These are arranged in pairs on each side of a central gangway and have well upholstered,

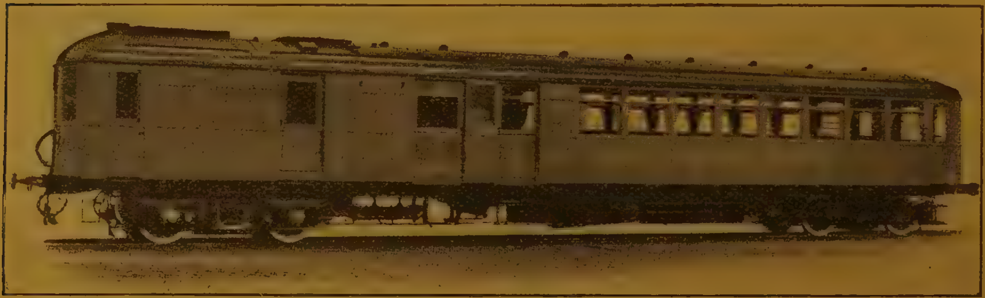


Fig. 1. — New 300-H. P. « Sentinel » railcar for the London & North Eastern Railway.

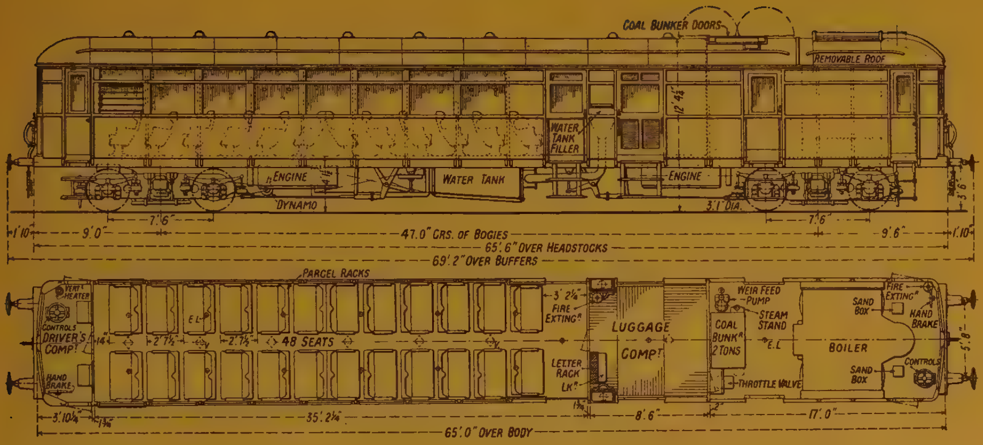


Fig. 2. — Elevation and sectional plan, showing seating and other arrangements, London & North Eastern Railway car.

deeply sprung seats with comparatively high backs similar to those supplied on long-distance road motor vehicles. Large windows extend down both sides giving wide views of the country traversed, each alternate window being arranged to open. Electric lighting on Stone's system gives brilliant illumination to all parts of the coach while steam heating and ample ventilation ensure perfect comfort in all weathers. The cars are capable of speeds up to 65 miles an hour so that they can hold their own when used for intermediate services amongst fast main line traffic.

A trial run took place during October 1932, a part of the route chosen being over the line from Whitby to Scarborough. Between Robin Hood's Bay and Ravenscar this includes a gradient some three miles long of 1 in 39. The car was brought to a stand near the bottom and the timings up the grade were carefully checked. The average speed on the gradient was 31.35 miles an hour, the last mile being done at a steady speed of 35 miles an hour. This establishes a new record for self-propelled vehicles on this line, the previous best for either steam or internal combustion driven cars being about 22 miles an hour.

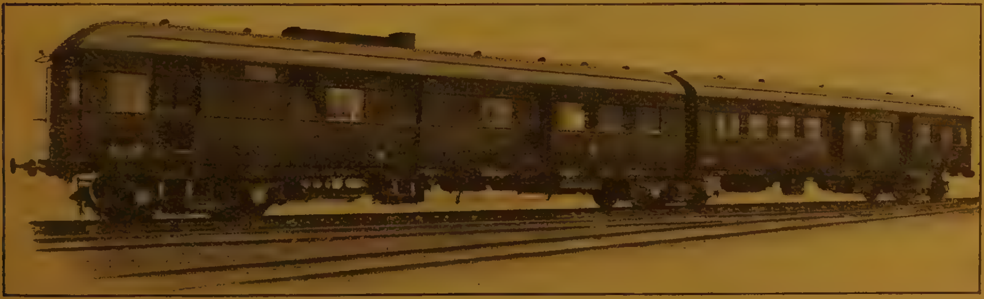


Fig. 3. — « Sentinel-Cammell » articulated unit, Roumanian State Railways.

The Roumanian cars.

The « Sentinel-Cammell » steam railcars for the Roumanian State Railways are of two types comprising six single units and two double articulated cars. Each of the six single-unit railcars consists of a single body mounted on two four-wheeled bogies, the power unit and control gear being supplied by the « Sentinel » Waggon Works Limited, and the remainder built by the Metropolitan-Cammell Carriage, Wagon & Finance Co. Ltd. at their Midland Works, Birmingham. The boiler compartment, which is arranged at the front end of the car, contains the boiler, water tank, oil tank, controls, sand-boxes, the air brake compressor, and other details, and the engine, of the standard « Sentinel » 100-150 H. P. type, has six cylinders (6-inch bore × 7-inch stroke) and is slung from the underframe at the rear of the front bogie, on to which it drives.

The boiler is of the standard « Sentinel » vertical water-tube type arranged for burning oil fuel, the working pressure being 300 lb. per sq. inch. The steam is superheated to a temperature of from 650° to 750° F. The drive is transmitted from the engine to a gearbox mounted on the driving axle by means of a cardan shaft. Constructed entirely of steel, the body of the car consists of a light but strongly built underframe on which the sides and roof are so arranged as to form a rigid structure of which they are integral parts, each bearing a portion of the stresses to which it is subject. The controls are provided in the boiler compartment and duplicated in a small driving compartment at the rear of the car, so that it can be driven with equal facility from either end. Brake-gear of the Westinghouse type is provided, as well as screw-operated handbrakes in each driving compartment.

Body interior.

The interior of the car comprises a second-class compartment to seat sixteen and a third-class compartment to seat thirty-nine, an entrance vestibule being arranged between the two compartments. Lavatories are provided for each

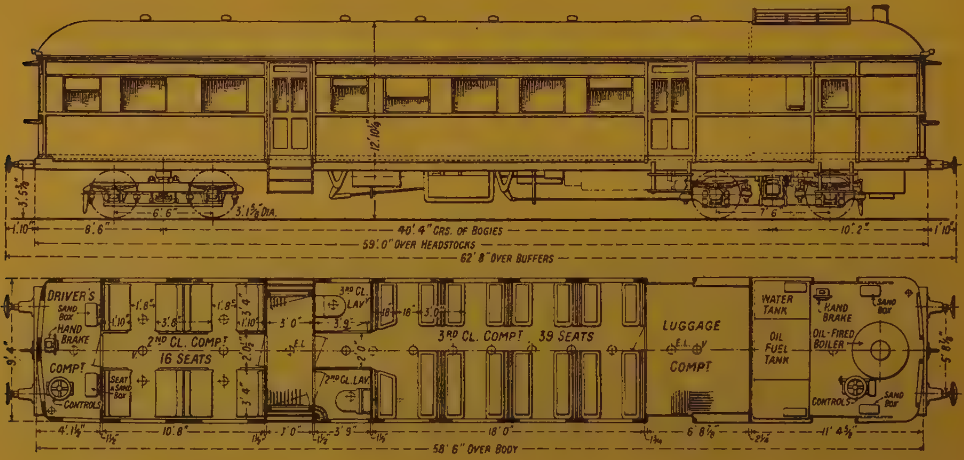


Fig. 4. — Elevation and sectional plan of « Sentinel-Cammell » car for the Roumanian State Railways.

class of passenger, and a small luggage compartment is placed next to the boiler compartment. All the windows of the car are of large size and are provided with metal-framed lights arranged to fall and equipped with fastenings, so that they can only be operated from the inside. The interior panelling in the passenger compartments is of « Sundeala », this being suitably decorated in each class. The seats are of the fixed back-to-back type, those in the second class being upholstered in Rexine and both backs and seats being comfortably sprung and padded. In the third class compartment the seats are covered with padded cushions, the back being of the lath-and-space type carried out in pitch pine. Steps and hand-rails are provided at all doorways so as to give easy access from the ground or low platforms.

The car is equipped with electric lighting on the « Dick « system, which has been adopted as standard for the Roumanian State Railways and provides for head and tail lamps at each end of the car as well as for ample lighting in the passenger compartments. Parcel racks are provided, and all windows are fitted with roller blinds. Steam heating is provided in the passenger compartments and in the rear driving compartment, the system being designed to suit the variations in temperature experienced in Roumania, while torpedo roof ventilators are also fitted in all compartments. The exteriors of the cars are finished in Wagons-Lits blue, with outside lettering in accordance with the Roumanian State Railways' requirements.

[625. 143.2 & 625. 143.3]

Steel rails and transverse fissures.

(*The Railway Engineer.*)

Chicago, Illinois, U. S. A.
January 3, 1933.

To the Editor of *The Railway Engineer.*

Sir,—Even at this great distance I have read various articles published in *The Railway Engineer* from time to time on the subject of steel rails and transverse fissures, and , as well, the editorial comment that you have frequently made on them. Often both have referred to American rails and conditions, particularly the prevalence in the United States of fissures and the menace to safe railroading that they entail. Certainly, congratulations to your authors and you are in order, because of the very excellent treatment accorded this vital subject, and especially because that treatment evidences a familiarity, as a whole, with our practices and difficulties that is indeed surprising, in view of the distance between us. My experience with the inspection and testing of rails at all of the mills on the American continent, a close follower of their later use in track, and more recently intimate association with the operation of the Sperry detector cars enables me to advance some ideas on the subjects covered. But in doing so, please understand that the following is offered not in any sense as a criticism but rather as appreciation and commendation, and with the hope that your interest will be kept awake and further timely aid be given us toward the solution of various mysteries surrounding transverse fissures.

In the first place, while admitting freely that, as a general proposition, our basic open-hearth steel rails (such as in almost universal use here for practically 20 years) are too « hard, » I am equally inclined to suspect that by the same indefinite yardstick of comparison yours are too « soft. » True, my reason for that statement is mostly limited to a contact I had with a rather large consignment of rails exported from here a few years ago to South Africa. Made with all the care and diligence possible for an exporter to put into his product being sent for use thousand of miles away, and which would carry his and his country's reputation for many years, the thought occurred to myself and others that a considerably better job could be done had we been permitted to increase the carbon content somewhat, and thus not only stiffen the rail but also harden it. I am fairly positive that a much better riding track (straighter rails for both line and surface) as well as much better wearing rail would have easily resulted with practically no attendant risks. Somewhere between the compositions specified for your rails and ours there must be some common ground which will satisfy our terrible requirements due to the volume of traffic and heavy wheel loads to which our rails are subjected, and at the same time, effect an improvement in the metal for your own rails, which I am surprised if there is not an actual need for. Your metallurgists and ours must find some new apportionment whereby the four or five usual elements and iron can be better associated without introducing risks now encountered by following some mere rule of thumb; such for example, as compensating for the omission of a little phosphorus by adding a little more carbon. Following such tactics here, without greater regard for sound metallurgical treatment, has led us to a lot of trouble, for as carbon has been increased transverse fissures now appear to predominate more in the higher carbon heats, much as certain soils produce abundant crops of wheat or corn. My point here is, that the field is wide open for constructive study of what may constitute the proportions of iron and the five common elements in order to provide the best steel for the purpose in mind. I think that subject has been too much a hapharzed one, for which some of the penalties being paid are the liability of undue segregation, the presence of sonims and various other defects, among which may be a predisposition for transverse fissures.

The present tendency is to regard transverse fissures as due to the « shatter cracks, » which in turn are the results of unequal stresses set up in the rails when *cooling on the hot beds.* The admirable work that my friends the Messrs. Sandberg have done to overcome some of these abuses is an inspiring invitation for better rails, and the results of their recommended practices will be awaited with great interest, particularly on the rails subsequently rolled here for our use. But frankly, and again with the greatest of respect, let me propose a word of caution, for while much good will in all probability result from the suggested slow cooling, I hesitate to think that the fissure problem will be definitely solved. Why ?

Because since about 1925, while most of our heavy-section rails have been stamped not only with the heat (or melt) number but a letter, A, B, C, D, etc., showing the location of the rail in the ingot from which it was made from the top down toward the bottom, there has been added another number serving to identify the particular rails from the same ingot. Thus 27492-F 17 stamped on a single rail means it is the 6th rail down from the top of the 17th ingot rolled from heat 27 492. It should be remembered that our heats may be upwards of 200 000 lb., from which perhaps 20 ingots each weighing from 9 000 to 14 000 lb. may be cast. A single ingot makes from 5 to 10 or 12 rails, depending on the mill and weight of the section being rolled. Results of this careful system of stamping, whereby the definite relationship of each rail can be established, are now being obtained, and certain information heretofore entirely unavailable is becoming increasingly important on rails less than about seven years of age.

Ordinarily the time that this stamping system has been in effect would be too short to permit of accumulating service records of rails indicative of anything pertinent. But Sperry detector cars locate internal defects in rails long before any surface manifestation of the defects occurs, so that ordinary records are greatly augmented by detector car records, and what might be considered as only symptoms are developing rapidly into outstanding indications which more time may result in definite conclusions. One important indication so far brought out is that transverse fissures appear to be not only prevalent in rails from certain heats, but (and this is the important point) also more prevalent in rails of various ingots of those heats than in other ingots. Rails from some ingots of a susceptible heat have produced absolutely no fissures while other ingots from the same heat have had their rails show a pronounced tendency to fissure. In some cases of six-rail ingots as many as four and five fissured rails have been found on one ingot, though rails from other ingots of the same heat have shown none. Thus suspicion is naturally directed to ingots as units as well as heats.

All of the rails rolled go over the hot beds and are thus subjected more or less to the same tendencies that may provoke shatter cracks. Only a few rails are apparently thus damaged. But those few appear now in frequent cases to be those born of the same ingots. Therefore it seems possible that something evil has happened to some of the ingots, and that one of the causes for fissures must be looked for in some other place than the hot beds. And of course, it will be freely admitted that these large high-carbon ingots frequently are given extremely drastic treatment in the soaking pits, if not in some of the prior practice of casting and stripping.

It must be remembered that rails are supplied to our United States roads at the rate normally of 2 250 000 tons per year. This amounts to roughly 13 000 miles of track. There is probably around 200 000 miles of main track on which new rail is laid, the remaining 75 000 miles of main-line trackage being laid with the rail replaced by the annual supply of new rail. Thus it might be said that roughly fifteen years would be required to relay all important trackage with new rail. The possibility, therefore, of replacing all the present rail with new and hopefully fissure-free rail is almost an overwhelming one.

It can only mean that there is bound to be work for detector cars for years to come, because no other means of locating internally defective rails in track has been found. Such testing periodically assures almost beyond peradventure a certain standard of safety that can be obtained in no other way, while also various economies in handling rails that you previously commented upon have been efficiently effected. American roads are fast realising the advantages of detector car testing, and now that the operation of one in France is being so warmly recognised it will doubtless spread to other European countries. Despite the common use of basic-Bessemer steel rails on French roads, the fact that transverse fissured rails are being found to practically the same extent as on basic open-hearth rails in America is interesting, if not disquieting, and as time goes on and other results of testing are available, detailed comparisons will be eagerly awaited.

May I not express the hope that the above will invite the publication of further pertinent matter by your correspondents and self.—Yours truly,

C. W. GENNET, JR.,
Vice-President, Sperry Rail Service.

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Our correspondent's interesting letter, while offering generous tribute to articles which have appeared from time to time in *The Railway Engineer* on modern rail conditions, is concerned chiefly with that in our May, 1932, issue, wherein a description was given of the Sperry detector car equipment (1) now employed regularly on American and Canadian railroads for the detection *in situ* of transverse fissure defects in rails. In our editorial comment on this article we drew attention to the high carbon contents common to American rail steel, and expressed surprise that more attention had not been paid in America to the possibility of arresting during manufacture the tendency of the rails to fissure, by such means as the retarded cooling of the Sandberg oven, for example. Since then the practice of retarded cooling has begun to make some headway in America, but we agree that for many years to come Sperry fissure detection methods will still be necessary, in view of the immense mileages in American tracks of high carbon rails, which have not been subject in manufacture to any special cooling precautions.

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(1) See also *Bulletin of the Railway Congress*, March 1929, p. 253 and March 1932, p. 283.

This letter confirms our view that hitherto in America closer attention has been paid to the conditions governing fissure failure than to the best method of fissure prevention. As a result of elaborate statistical survey, it has been proved that the highest carbon casts are in general more susceptible, but the most striking feature of the investigation has been the variation of susceptibility between casts whose composition and general manufacturing record have been similar. Also, the writer of the letter further points out that there may be a similarly varied susceptibility even between two ingots from the same cast. From this he argues that ingot conditions — that is, casting, stripping, and soaking-pit practice — may be as much responsible for fissured rail-heads as rail cooling conditions on the hot-banks, but with this conclusion we confess that we are unable to agree. Large secondary piping fissures, in the longitudinal plane of the rail, can certainly be caused in this way, and such defects, ultimately causing split rail-heads, could not be cured by oven treatment of the rails. But the fact that the rails from certain casts and certain ingots are immune from fissuring is no argument against the general application of retarded cooling. Not every human being is equally susceptible to smallpox infection; vaccination, nevertheless, is generally enforced, with a view to arresting the tendency to infect, and so guarding against an epidemic. Similarly the fact that retarded cooling of rail has proved itself efficient in arresting the tendency of the rails to fissure justifies the general application of the process, on the ground that prevention is better than cure. And as broken rail records and the subsequent use of a Sperry car has proved the existence of fissure trouble on an extensive scale on the Continent also, where comparatively low carbon rails are used, the desirability of applying retarded cooling to all descriptions of rail, both high and low carbon, is further emphasised.

But here we have merely the negative side of the rail problem; the positive side is the increasing need for better wear. And here again, while we appreciate our correspondent's claim that high carbon contents are essential in American rail practice, in order to provide sufficient resistance to deformation under American axle-loads — which in general are 50 %, above the average figures here — we cannot agree that the British rail, in virtue of its lower-carbon percentage, is too « soft. » The writer of the letter expresses himself as positive that a higher-carbon content would produce « straighter rails, both for line and surface, » than could be obtained by the rail analyses current in this country. We wonder if he can have perused the article in our January, 1932, issue, describing some research which had been conducted on early London and North Eastern Railway rails, in which the author mentioned that attention was first directed to these rails by the perfect « top » that they maintained after 40 years' service in a secondary main line; yet the first rail taken out for analysis and tests proved to contain no more than 0.35 % of carbon ! Furthermore, the weight of evidence, during the past few years, has proved beyond question that excessively high-carbon contents in rails defeat their own object; hard such rails undoubtedly are, but with a hardness that powders away under traffic. The lowering of carbon contents on three of the four British group railways by an average of 0.05 %, accompanied by an increase in manganese to an average of 1.00 %, has, on the other hand, increased wearing capacity by roughly 30 %.

This modification of analysis, however touches no more than the fringe of the problem. The prime requisite in the railway rail is not hardness, but toughness. In the article already mentioned, on early rail tests, the suggestion was advanced that wear-hardening and age-hardening of the running surface of the rails were, in conjunction with the analyses of the rails, and the rolling methods of their time, jointly responsible, in all probability, for their phenomenal wearing capacity. The fact is that these earliest steel rails were, in their capacity to wear, vastly in advance of the traffic conditions which obtained when they were first laid. Consequently, they had ample time to benefit by work-hardening and age-hardening before the serious effects of wear and heavier loads began to be felt, and by that time they had become equipped with new powers of resistance. For this reason it does not follow that rails made to-day to the same analyses and in the same rolling conditions would give anything like the same proportionate wear results; they would have no corresponding opportunity, under modern traffic, to wear-harden and age-harden in the first stage of their use. The moral seems to be that we need, not merely to juggle with the percentages of our existing rail-steel analyses, as our correspondent's letter suggests, but to discover new methods of alloying and heat-treating our rails, on safe lines, so that once again they may have the opportunity of work-hardening even in modern traffic conditions. Rails made of manganese alloy demonstrate this capacity to work-harden in no uncertain fashion, but at a cost which is prohibitive except in locations where rail wear is of exceptional severity. The production of a rail steel which will work-harden similarly at an addition to the cost of, say, no more than 50 %, offers a very attractive field of research to the steel-rail expert to-day. — (Ed. — *The Railway Engineer.*)

MISCELLANEOUS INFORMATION.

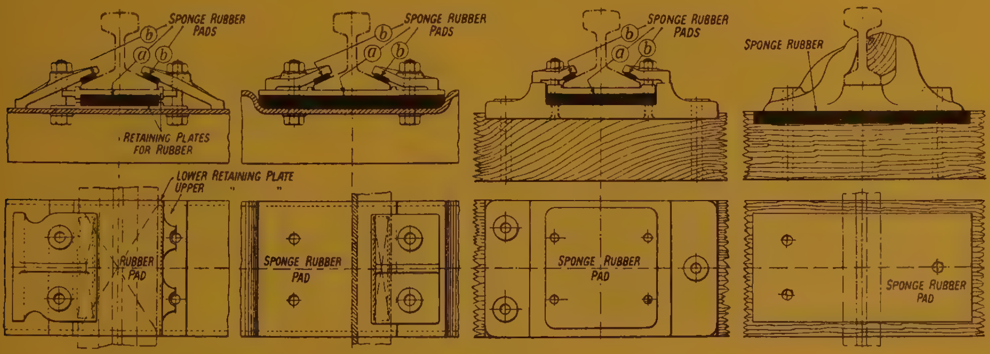
[625. 14]

1. — Shock and sound-absorbing permanent way.

(The Railway Gazette.)

Attention has already been called in these columns to the fact that the permanent-way engineer is now faced with new problems introduced by electrification and also in many countries by the substitution of steel for wooden sleepers. Not the least of these problems is the provision of a track which is at once sufficiently rigid to carry heavier unsprung loads and yet will absorb vibration and run quietly. In other words, he must find the best means of reducing or obviating the transmission of shock and audible frequencies from the permanent way to the coaching stock.

Considerable research work has already been carried out, first to ascertain where the principal source of the trouble lay, and the passage it took, and secondly to prevent or reduce to a minimum the transmission of vibration to vehicles. Gratifying results of experiments are reported, especially in connection with that noisiest of all roads which has a flat-footed rail carried on a steel sleeper. These were obtained (1) by insulating the chair or bearing plate from the sleeper by bedding it in a material which would absorb shock and audible frequency and (2) by again using the same material to insulate the rail itself from the clamping fastenings which secure it.



One outcome of these investigations has been the patent which will now be briefly described and to which the illustrations above refer, though it should be noted that the latter do not pretend to be detail drawings and are, in fact, little more than diagrammatic. The patent is fully covered in conformity with the provisions of section three (6) of the Patents and Designs Acts, 1907/1932, under Folio No. 34574-32 dated 6/12/32 under the heading of « Improvements in or relating to Rail and Tramway Tracks » and it is claimed that the application of this patent to steel-sleepered track definitely reduces some of the objections to it. A modification of the patent has been made to cover the requirements of the standard British chaired and keyed permanent way, by the provision of a suitable shock and/or audible frequency absorbing device under the chair self.

The main feature of the invention covered by this patent is the use of a pad or layer of shock-absorbing and sound-deadening material, preferably sponge rubber of suitable density, which by experiment has been found the most successful material, due to its sound-deadening and sound-absorbing properties. It is moreover unaffected by climatic conditions, and under extreme and varying pressure is not permanently deformed and returns to its normal conformity more rapidly than other material with which experiments have so far been made. This pad is employed as shown in the accompanying illustrations with various forms of chair, bearing plate and sleeper and in the positions showns (*a*) between sleeper and chair or bearing plate and (*b*) between rail and clamping fastening.

From left to right of the illustrations there is first of all the simplest from of track with two recessed bearing plates having a shock-absorbing pad (*a*) between them, both being held in position by their ends being grooved to engage the rail clamping bolts. Next there is a type of track having a dished sleeper, the pad (*a*) lying in the recess so formed and under the bearing plate. The bolts here pass through the bearing plate and pad holding them in correct position.

Where a chair is used, pad (*a*) may be accommodated in a recess in the chair with a bearing plate between it and the rail, and is clamped in position by the bolts which pass through it as depicted in the drawing. The pads in position (*b*) are in all cases accommodated in recesses in the clamping jaws as shown, and it is claimed that when used in conjunction with those in position (*a*) they give to the rail a resilient shock-absorbing suspension as well as damping the passage of vibrations of audible frequency.

Other advantages claimed for this patent are that it tends to prevent or reduce rail creep and may be used with longitudinal as well as transverse sleepers, as for example, on bridges. The deadening of vibration should also tend to prevent rail fastenings from working loose, prolong the life of vehicle springs and fittings and generally reduce normal maintenance of both permanent way and rolling-stock. Additional details required for the strict preservation of gauge and for adjustment of the same have been considered in a general way, but are left to the permanent-way engineer to perfect, the patent covering merely the general idea outlined above. As will be seen, it is applicable to practically every kind of permanent way in general use, and should at least provide a basis for consideration of the principles involved. Further particulars may be obtained from the joint patentees, Mr. B. S. Davies, of « Wyndcote », Horsell Rise, Woking and Mr. P. A. Summers, of « Micklehurst », Grove Road, Osterley.

[**656. 259** (.42)]

2. — The Cooke fog penetrating lamp.

(The Railway Gazette.)

For several years now the officers of the London & North Eastern Railway have been experimenting with electric lights giving a powerful concentrated beam, in order to ascertain whether the results were such as would enable fogmen to be dispensed with, and at the same time to secure the same efficiency in the indications given by mechanical signals as obtained with modern colour light signals, and the results up to date have been eminently satisfactory. Quite a number of these lamps are in permanent use and further installations are contemplated. Cooke, Througton & Sims, of York, have now developed, in collaboration with the railway company, a new lamp incorporating important improvements.

So far as beam intensity, coupled with wattage required, is concerned, it is considered that this lamp is more efficient than the most modern colour light signal. In proof of this the lamp employed is an 8-volt 5-watt lamp, and in a test carried out, gave an illuminating power of 41.7 foot-candles over an area of 4.05 sq. feet at a distance of 31 ft. 4 in., this corresponding to a beam of 41 100 candle power.

A mangin mirror is mounted behind the lamp and the rays are collected from it and reflected forward in a parallel beam. Light that would be wasted from the front of the lamp is collected by the silvering on the front portion of the bulb and reflected back across the filament to the mangin mirror where it is reflected forward in a parallel beam. The mirror and bulb are both mounted on the focussing gear which in turn is mounted in a ball seating in the back of the lamp. By means of a focussing screw the lamp may be moved backwards and forwards along the axis of the mirror in order to get a parallel or slightly diverging beam as required. The body of the lamp is cylindrical in shape, about 7 3/4 inches outside diameter, 6 1/2 inches long, made of an aluminium alloy. There is a plain glass window in the front held in a watertight frame, and the back of the lamp is a hinged cover carrying the mirror and bulb. This cover is hinged at the top and secured at the bottom by a wing nut and swivelling bolt giving easy access for changing the bulb. Mounted on the back cover is a small hinged box giving access to the focussing screw.

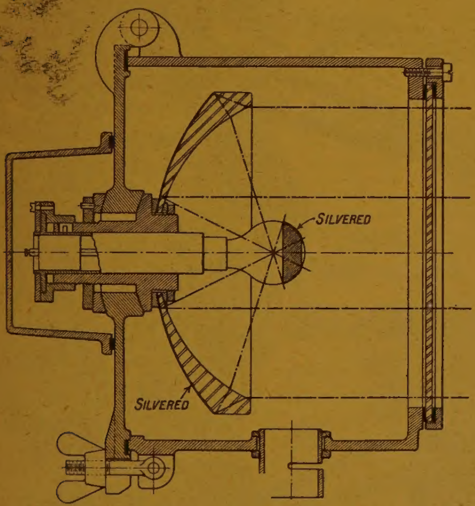


Diagram of the new fog penetrating lamp.

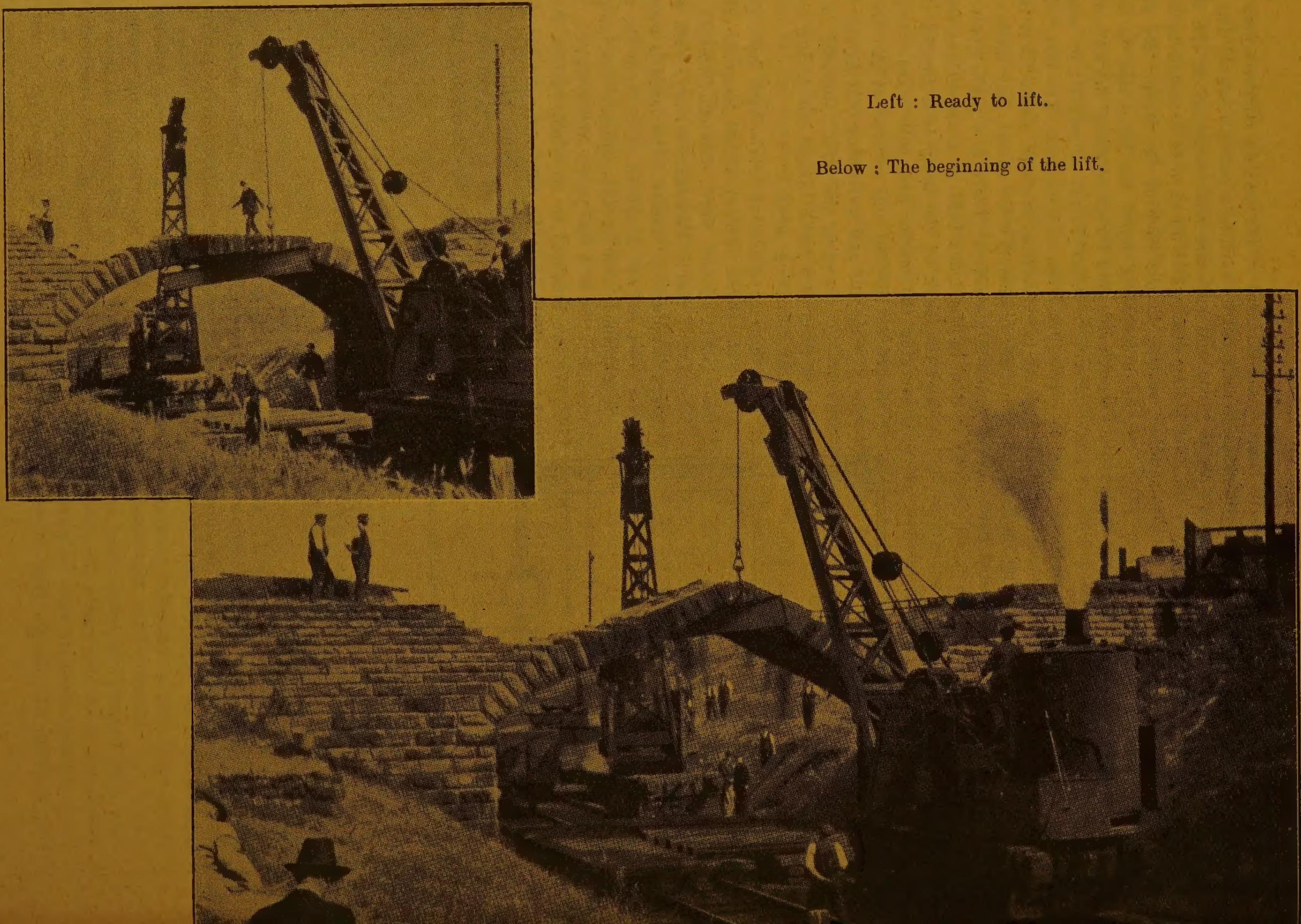
Several comparative trials have been made with the Cooke railway signal lamp on different parts of the North Eastern Area of the London & North Eastern Railway, with entirely satisfactory results. The lamp is usually focussed so that a spread of 2° from the axis is obtained, and at this spread the lamp is visible at over 1 000 yards in daylight.

We are indebted to Mr. John Miller, B. E., LL. D., M. Inst. C. E., Engineer, and Mr. A. E. Tattersall, M. I. E. E., Signal and Telegraph Engineer, North Eastern Area, London & North Eastern Railway, for the foregoing particulars.

[625. 13 (.42)]

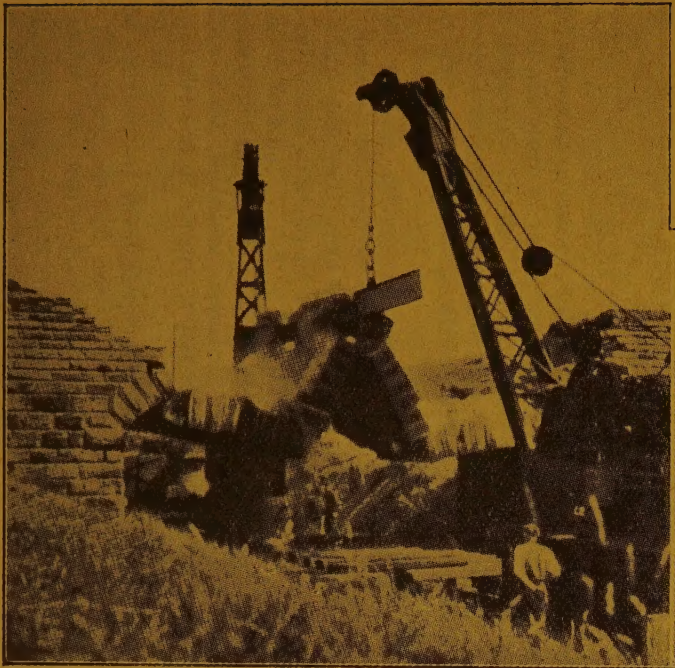
3. — Demolishing a masonry arch on the London and North Eastern Railway.

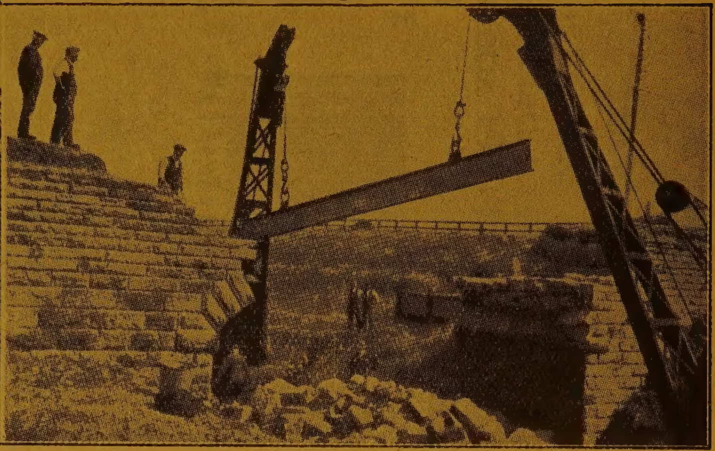
(The Railway Gazette.)



Left : Ready to lift.

Below : The beginning of the lift.





Left : Eighty tons of masonry in mid-air.

Below : The debris.

The above illustrations show an ingenious method of demolishing a bridge by lifting a joist through the crown of the arch after removal of the parapets and part of the haunching. The bridge, situated a few miles north of Newcastle on the London & North Eastern Railway main line, was replaced by a span of second-hand girders in order to allow of the elimination of a dip in the line which made drainage difficult.